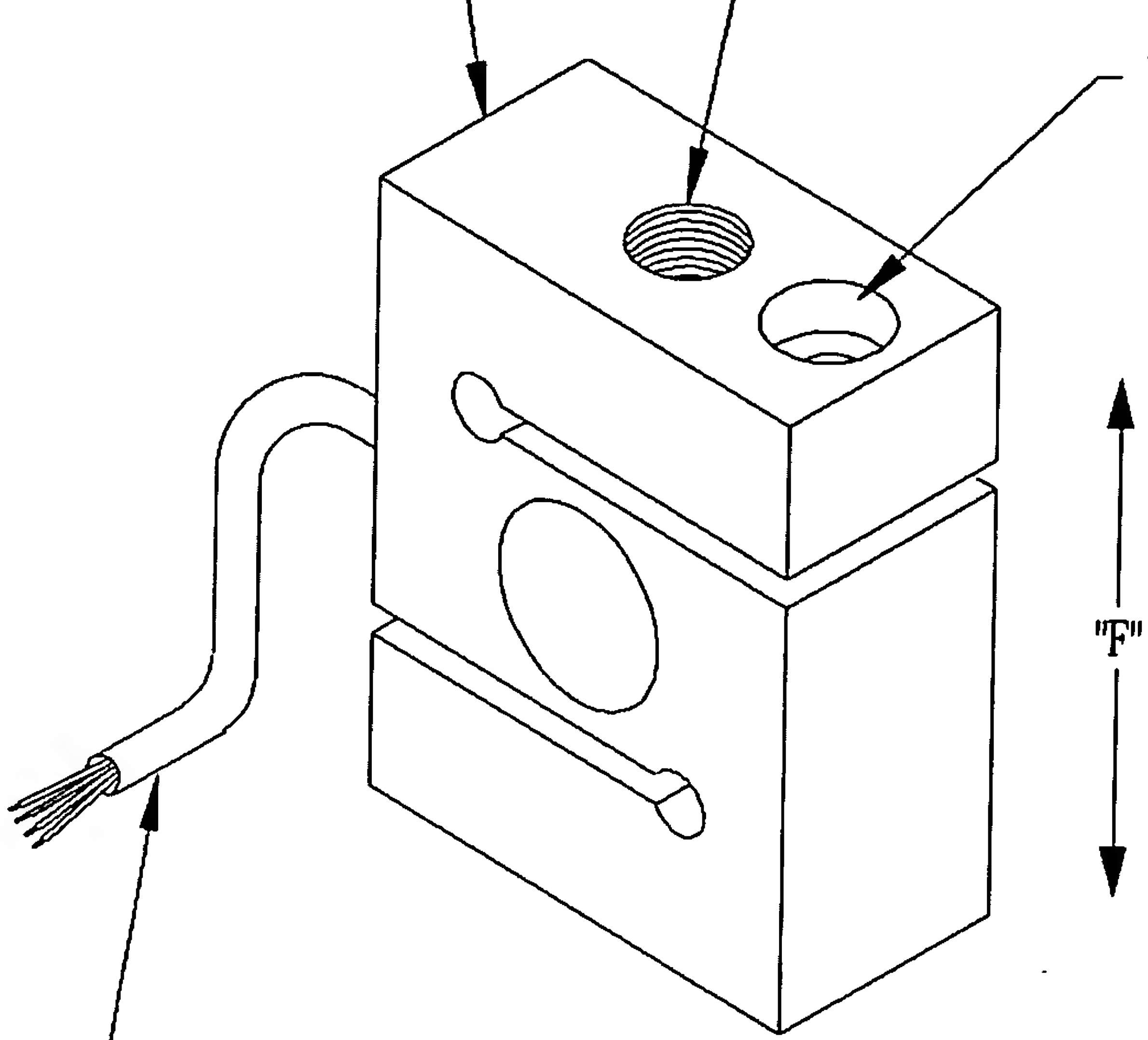
L Number	Hits	Search Text	DB	Time stamp
5	342	strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 11:05
6	259	(strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (deflect$5 bend$3 compress$3 tension$3)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 11:05
7	113	((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (deflect$5 bend$3 compress$3 tension$3)) and (wheatstone bridge)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 12:04
19	253	(strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (weight$3 load$3) near3 sensor	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 12:05
20	187	((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (weight$3 load$3) near3 sensor) and (deflect$6 flex$6 bend$3)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 12:05
21	101	(((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (weight$3 load$3) near3 sensor) and (deflect$6 flex$6 bend$3)) not (((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (deflect$5 bend$3 compress$3 tension$3)) and (wheatstone bridge))	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 12:06
23	11778	(weight load$3) same (cell sensor) same strain	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:20
24	307	vehicle same seat and ((weight load$3) same (cell sensor) same strain)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:21
25	243	(vehicle same seat and ((weight load$3) same (cell sensor) same strain)) and (deflect$5 flex$5 bend$3 compres$3 tension)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:25
26	70	((vehicle same seat and ((weight load$3) same (cell sensor) same strain)) and (deflect$5 flex$5 bend$3 compres$3 tension)) not ((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (deflect$5 bend$3 compress$3 tension$3))	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:41
31	32	(strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) not (((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (deflect$5 bend$3 compress$3 tension$3)) (((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (deflect$5 bend$3 compress$3 tension$3)) and (wheatstone bridge)) ((strain near3 (gaug$3 gage gag$4) and (seat$3 occupant) near6 weight$3) and (weight$3 load$3) near3 sensor))	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:44
32	6586	strain near10 sensor and (weight load$3)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:45

33	4810	(strain near10 sensor and (weight load$3)) and (deflect$5 flex$6 bend$3 deform$3 compres$5 tension)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:50
34	795	((strain near10 sensor and (weight load$3)) and (deflect$5 flex$6 bend$3 deform$3 compres$5 tension)) and load$3 near4 cell	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/07/07 14:51

PRECISION "S" LOAD CELL
UNIVERSAL: TENSION & COMPRESSION
M2300 MODEL
CAPACITIES: 250, 500, 750, 1K LBS.



TYPICAL APPLICATIONS

HIGHEST ACCURACY, MOST ECONOMICAL UNIVERSAL LOW CAPACITY LOAD CELL: USED IN AIRCRAFT TURBINE BALANCING MACHINES, WELD FORCE MACHINES, AND AUTOMOTIVE DYNAMOMETERS.

"DO NOT ALTER WITHOUT AGENCY NOTIFICATION "

FM APPROVED

INTRINSICALLY SAFE AND NONINCENDIVE FOR CLASS I, II, III, DIV. 1 & 2, GP A-G HAZ. LOCATION PER DWG. 50010
TEMP CODE T4 @ 85°C

SPECIFICATION

OUTPUT:	1.5 mV/V
NON-LINEARITY:	.02% F.S.O.
HYSTERESIS:	.05% F.S.O.
ZERO BALANCE:	± 1%
COMP. TEMP. RANGE:	0 to150°F
SAFE TEMP. RANGE:	-40 to180°F
TEMP. EFFECT. ON OUTPUT:	.0015%/°F
TEMP. EFFECT ON ZERO:	.0020%/°F
TERMINAL RESISTANCE:	1000 OHM
EXCITATION VOLTAGE:	1-15 VDC
SAFE OVERLOAD:	180 %
RINGING FREQUENCY TYP	>5000 HZ

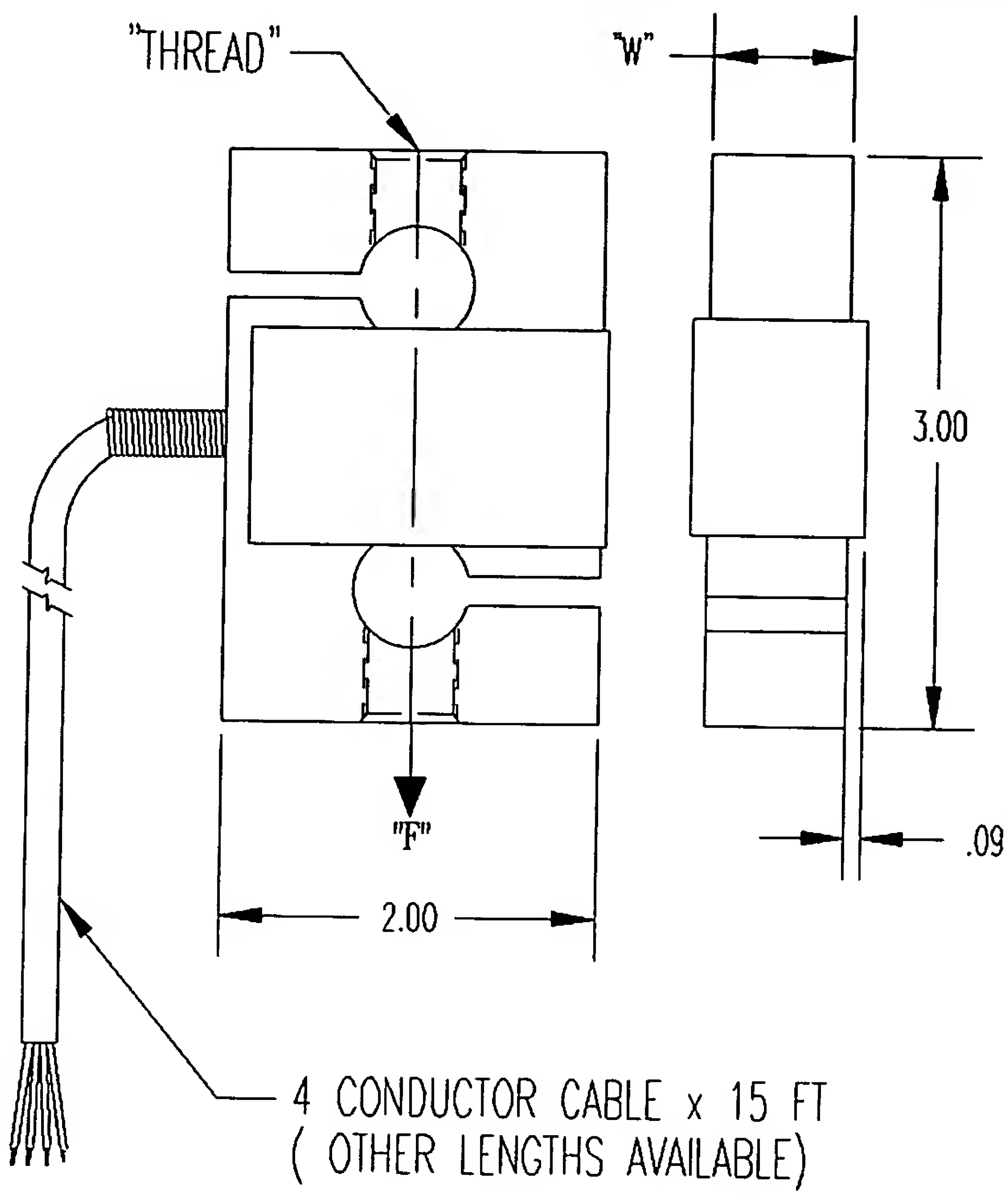
3 YEAR WARRANTY

OPTIONS: OPERATING TEMP., CABLE LENGTH, 0-5V, 4-20mA
S.S. ARMORED CABLE, TEFLON CABLE, CALIBRATION.
MIL-STD 45662, OTHER OPTIONS OR VARIATIONS AVAILABLE.

SAFETY CONSIDERATIONS: Always use load cells below the specified load rating. Load applied must be in the primary load axis. Extraneous loads or compound stress must be avoided. De-rate load cell maximum load or supply safety hardware where failure could cause injury or damage. (I.E. safety chains, safety rods etc.) Do not jerk load or apply load at high rate of speed. Inspect routinely for damage excessive wear or corrosion, replace if found. Consult a qualified engineer prior to use.

PRECISION "S" LOAD CELL
TENSION APPLICATIONS
M2405 MODEL

CAPACITIES: 250, 500, 750, 1K, 1.5K, 2K, 2.5K & 3K LBS.
STAINLESS STEEL CONSTRUCTION



TYPICAL APPLICATIONS

VERY LOW COST TENSION "Z" CELL USED FOR ALL GENERAL PURPOSE FORCE MONITORING NEEDS. WHERE GOOD PERFORMANCE IS REQUIRED. COMPACT DESIGN, OUTDOOR ENVIRONMENT RESISTANT.

CAPACITIES (POUNDS)	"W" DIM	"THREAD"
75# TO 125#	.50	1/4-28UNF-2B THRU
150# TO 3K	.88	1/2-20UNF-2B THRU

FM APPROVED

INTRINSICALLY SAFE AND NONINCENDIVE FOR CLASS I, II, III, DIV. 1 & 2, GP A-G HAZ. LOCATION PER DWG. 50010 TEMP CODE T4 @ 85°C

SPECIFICATION

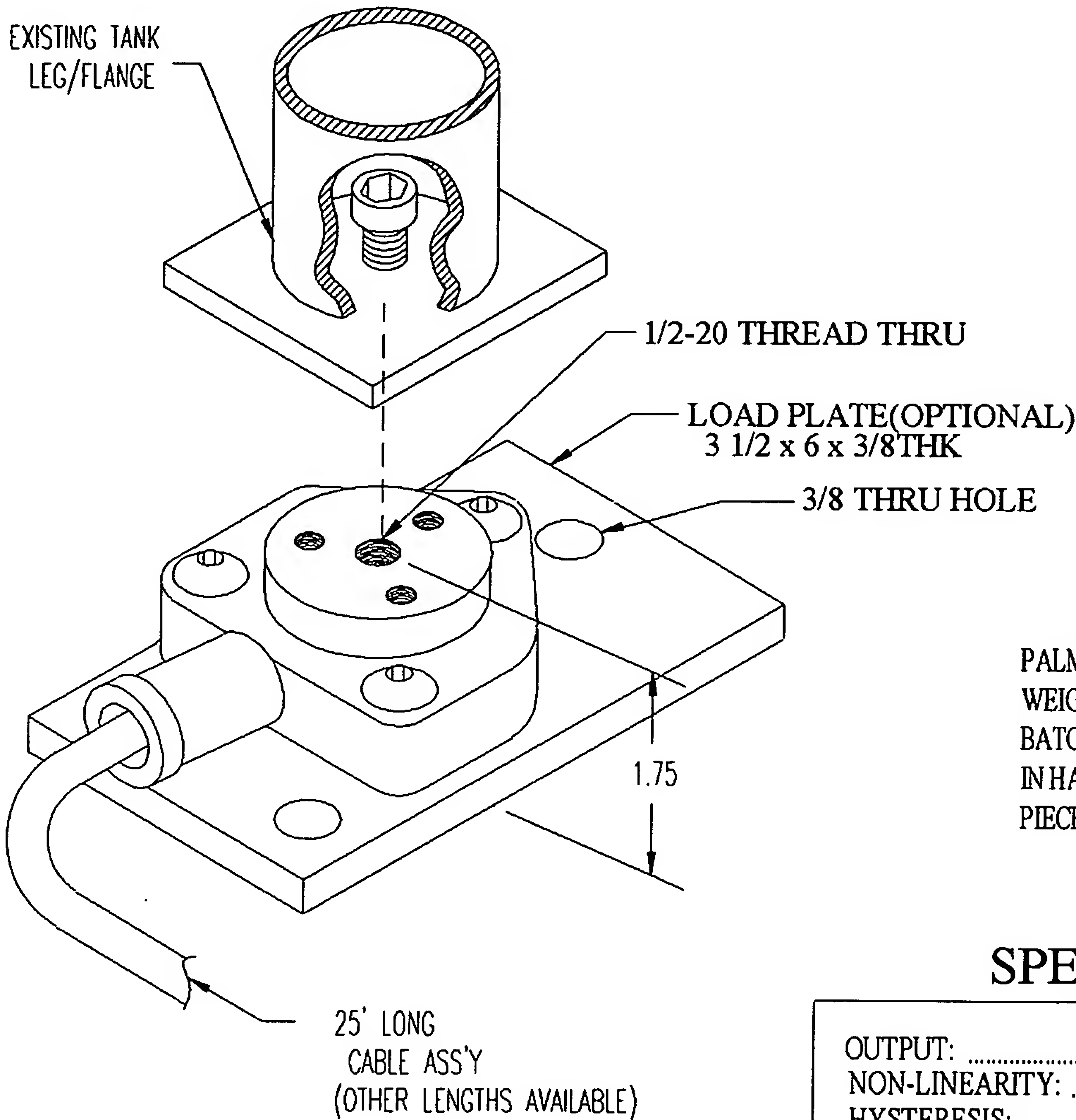
OUTPUT:	2.0 mV/V
NON-LINEARITY:	.02% F.S.O.
HYSTERESIS:	.03% F.S.O.
ZERO BALANCE:	± 1%
COMP. TEMP. RANGE:	0 to 150°F
SAFE TEMP. RANGE:	-40 to 180°F
TEMP. EFFECT. ON OUTPUT:	.0007% /°F
TEMP. EFFECT ON ZERO:	.0013% /°F
TERMINAL RESISTANCE:	350 OHM
EXCITATION VOLTAGE:	0-15 VDC
SAFE OVERLOAD:	180%
RINGING FREQUENCY TYP	> 7000 HZ

OPTIONS: OPERATING TEMP., CABLE LENGTH, 0-5V, 4-20mA S.S. ARMORED CABLE, TEFLON CABLE, CALIBRATION, MIL-STD 45662, OTHER OPTIONS OR VARIATIONS AVAILABLE.

SAFETY CONSIDERATIONS: Always use load cells below the specified load rating. Load applied must be in the primary load axis. Extraneous loads or compound stress must be avoided. De-rate load cell maximum load or supply safety hardware where failure could cause injury or damage. (I.E. safety chains, safety rods etc.) Do not jerk load or apply load at high rate of speed. Inspect routinely for damage excessive wear or corrosion, replace if found. Consult a qualified engineer prior to use.

HIGH PURITY
MINI BEAR PAD ™
M7200 TUFF SERIES MODEL

CAPACITIES: 250, 500, 1K, 2.5K & 5K LBS.



TYPICAL APPLICATIONS

PALM SIZED FOR EXTREMELY LOW PROFILE WEIGHING. IDEAL FOR VESSEL WEIGHING, BATCHING AND INVENTORY CONTROL. USED IN HARSH WASHDOWN AREAS. UNIQUE ONE PIECE DESIGN FOR HIGH ACCURACY.

SPECIFICATION

OUTPUT:	2.0 mV/V
NON-LINEARITY:	.03% F.S.O.
HYSTERESIS:	.03% F.S.O.
ZERO BALANCE:	± 1%
COMP. TEMP. RANGE:	0 to 150°F
SAFE TEMP. RANGE:	-40 to 180°F
TEMP. EFFECT. ON OUTPUT:	.0007%/°F
TEMP. EFFECT ON ZERO:	.0015%/°F
TERMINAL RESISTANCE:	1000 OHM
EXCITATION VOLTAGE:	6-15 VDC
SAFE OVERLOAD:	300%

"DO NOT ALTER WITHOUT AGENCY NOTIFICATION"

FM APPROVED

INTRINSICALLY SAFE AND NONINCENDIVE FOR CLASS I, II, III, DIV. 1 & 2, GP A-G HAZ. LOCATION PER DWG. 50010
TEMP CODE T4 @ 85°C

OPTIONS: OPERATING TEMP., CABLE LENGTH, 0-5V, 4-20mA, S.S. ARMORED CABLE, CALIBRATION, MIL-STD 45662, OTHER OPTIONS OR VARIATIONS AVAILABLE.

SAFETY CONSIDERATIONS: Always use load cells below the specified load rating. Load applied must be in the primary load axis. Extraneous loads or compound stress must be avoided. De-rate load cell maximum load or supply safety hardware where failure could cause injury or damage. (I.E. safety chains, safety rods etc.) Do not jerk load or apply load at high rate of speed. Inspect routinely for damage excessive wear or corrosion, replace if found. Consult a qualified engineer prior to use.

Load Cell Designs

Strain Gage C nfigurati ns

The spring elements in a load cell (also called the "beam") can respond to direct stress, bending, or shear. They are usually called by names such as bending beam, shear beam, column, canister, helical, etc. (Figure 7-3). The two most popular designs for industrial weighing applications are the bending beam and the shear beam cells.

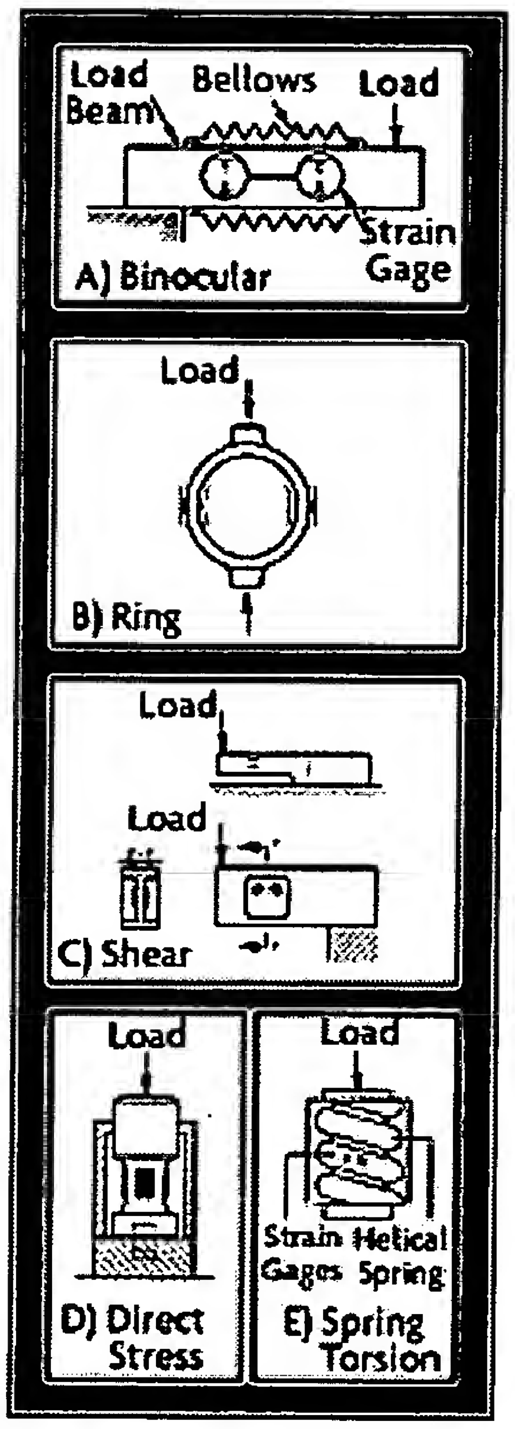


Figure 7-3: Load Cell

Spring Elements

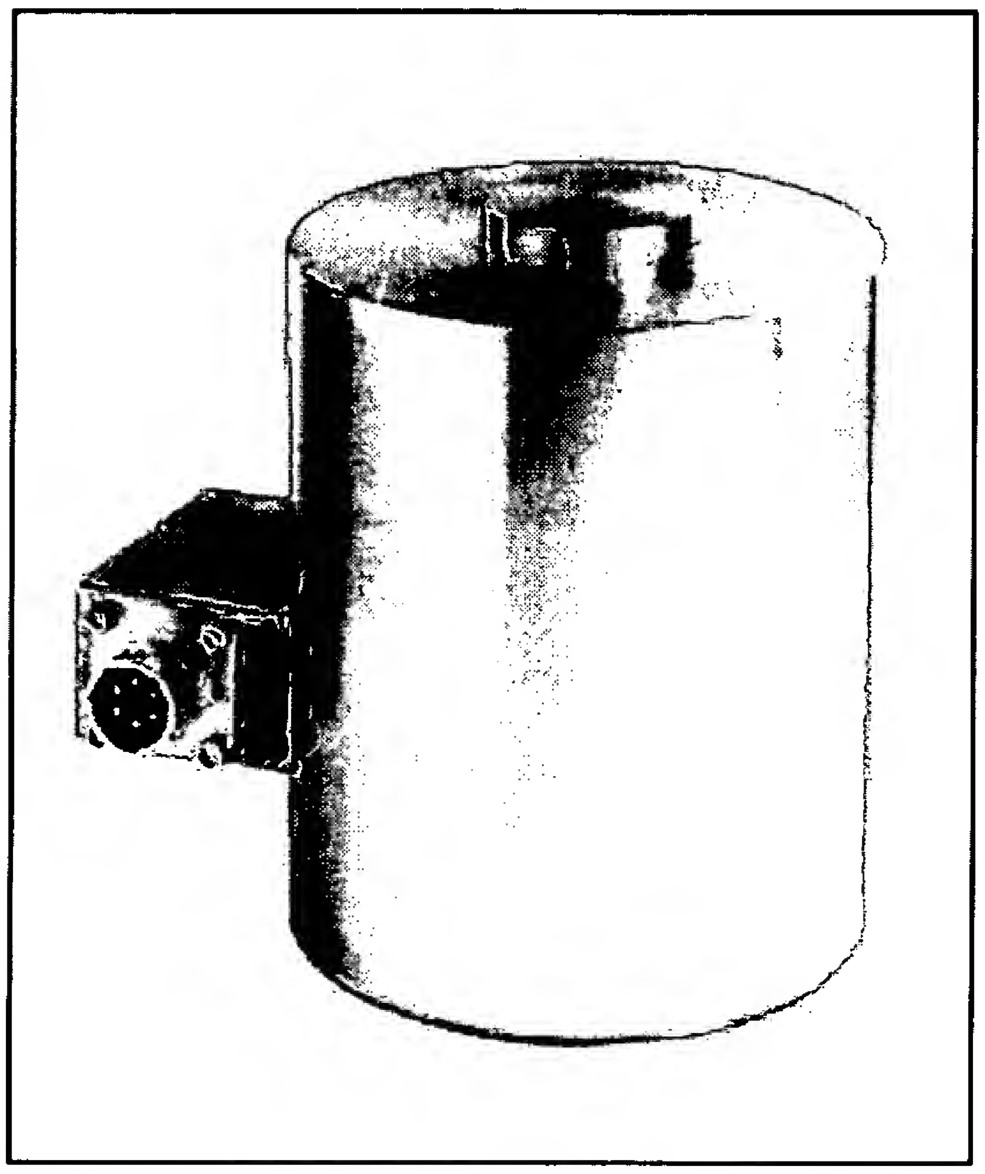
The **bending beam** sensor is one of the most popular load cell designs because of its simplicity and relatively low cost. It consists of a straight beam attached to a base at one end and loaded at the other. Its shape can be that of a cantilever beam, a "binocular" design (Figure 7-3A) or a "ring" design (Figure 7-3B). Strain gages are mounted on the top and bottom to measure tension and compression forces. Because the strain gages are vulnerable to damage, they are typically covered by a rubber bellows. The beam itself often is made of rugged alloy steel and protected by nickel plating.

In medical instrumentation, robotics, or similar low-load applications, smaller mini-beam sensors are available for measuring loads of up to about 40 pounds (18 kg). For loads up to 230 grams, the beam is made of beryllium copper, and for larger loads stainless steel is used. In this design, strain gages typically are protected by a urethane coating.

Ring or **pancake** designs are round and flat bending beam sensors consisting of bonded foil strain gages encapsulated in a stainless steel housing. The entire package resembles a flat pancake (Figure 7-3B). Compression-only sensors can be mounted in a protective, self-aligning assembly that limits load movement and directs the load toward the center of the pancake. Compression-tension designs have a threaded hole running completely through the center of the sensor.

Stabilizing diaphragms are welded to the sensing load button.

Shear beam sensors measure the shear caused by a load. A bending beam sensor cannot measure shear, because shear stresses change across the cross section of the cell. In a shear sensor, the I-beam construction produces a uniform shear that can be accurately measured by strain gages. A shear beam sensor (Figure 7-3C) is provided with a pair of strain gages installed on each side of the I-beam, with grid lines oriented along the principal axes. Advantages of a shear beam sensor over a bending beam include better handling of side loads and dynamic forces, as well as a faster return to zero.



Typical high-capacity canister load cell,

Direct stress (or column/canister) load cells are essentially bending beam sensors mounted in a column inside a rugged, round container (Figure 7-3D). The beam sensor is mounted upright, with two of the four strain gages mounted in the longitudinal direction. The other two are oriented transversely. The column may be square, circular, or circular with flats machined on the sides to accommodate the strain gages.

If provided with a rocker assembly or with self-aligning strut bearings, a canister load cell can tolerate a certain amount of tank movement and is relatively insensitive to the point of loading. Also, the canister protects the strain gages from physical and environmental damage. Canister cells range in size from 1-1/2 in. diameter "studs" with 100-500 lb. capacity to 6-1/2 in. diameter compression cells suitable for weighing trucks, tanks, and hoppers up to 500,000 lb.

Helical load cells are better able to handle off-axis loading than are canister-type compression cells (Figure 7-3E). The operation of a helical load cell is based on that of a spring. A spring balances a load force by its own torsional moment. The torsional reaction travels from the top of the helix to the bottom. By measuring this torsional moment with strain gages mounted on the spring, a helical load cell can provide reasonably accurate load measurement without the need for expensive mounting structures. Forces caused by asymmetrical or off-axis loading have little effect on the spring, and the strain gage sensors can measure both tension and compression forces.

A helical load cell can be mounted on rough surfaces, even where the upper and lower surfaces are not parallel, and total error can still remain within 0.5%. The helical load cell also is resistant to shock and

overload (it can handle a thousandfold overload), making it ideal for force or load measurements on vehicle axles, seats, or in forklift applications.

Button and flat washer bonded strain gage load cells are available in sizes from 1/4 to 1-1/2 in. diameter. The smallest sensors are available only in compression styles, but some of the larger cells have threaded holes for also measuring tension. While most of the tiny sensors handle up to about 200 lb., some are capable of measuring up to 50,000 lb. Because these little cells have no fixtures or flexures, off-axis loading and shifting loads cannot be tolerated. On the other hand, button and flat washer load cells are extremely convenient and easy to use. Even the smallest sensor is built of stainless steel, has a built in, full four-arm Wheatstone bridge, and can measure up to 200 lb. at temperatures up to 1500iF.

References & Further Reading

Omegadyne Pressure, Force, Load, Torque Databook, Omegadyne, Inc., 1996.

The Pressure, Strain, and Force Handbook, Omega Press LLC, 1996.

Elements of Electronic Instrumentation and Measurements, 3rd Edition, Joseph J. Carr, Prentice Hall, 1996.

Industrial Control Handbook, E.A. Parr, Butterworth-Heinemann, 1995.

Instrument Engineers' Handbook, Bela Liptak, CRC Press LLC, 1995.

Process/Industrial Instruments and Controls Handbook, 4th Edition, Douglas M. Considine, McGraw-Hill, 1993.

Van Nostrand's Scientific Encyclopedia, Douglas M. Considine and Glenn D. Considine, Van Nostrand, 1997.

Weighing and Force Measurement in the '90s, T. Kemeny, IMEKO TC Series, 1991.

Top of Page

Next Chapter: Force, Acceleration & Torque

DIGITAL FORCE INDICATORS WITH.......................

Portable Indicator

Great f r maintenance, quality c ntrol and other special applications throughout the plant

√ Extruder, piston, or stamper compression force
√ Machine foot load stress or weight
√ Measuring spring force √ Printer compression
√ Shock absorber testing √ Cable load tension

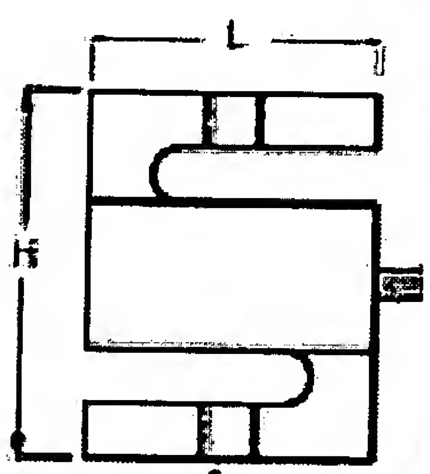
- **Provides excitation voltage for load cells and gives readout of applied force in lbs (or torque in inch-lbs)**
- **Easy to operate...no training needed**
- **4.5 digit (19999) LCD display**
- **Peak hold: captures the highest static or dynamic force reading until reset**
- **Response / update time for display <1 msec**
- **User-selectable decimal point position**
- **Push button resistance shunt calibration**
- **Span and balance adjustments on front panel**

HOW TO ORDER

PHM100 Portable Force Indicator. Includes 9V battery. Order load cells separately. All are compatible..............
M175 Belt Loop Carrying Case..................................
B9190 Deluxe Case. Padded protection. 9 x 12 x 5"...

Universal Precision "S-Beam" Tension or Compression Load Cells *

Overall Accuracy ±0.05%



THREAD TYPICAL BOTH ENDS

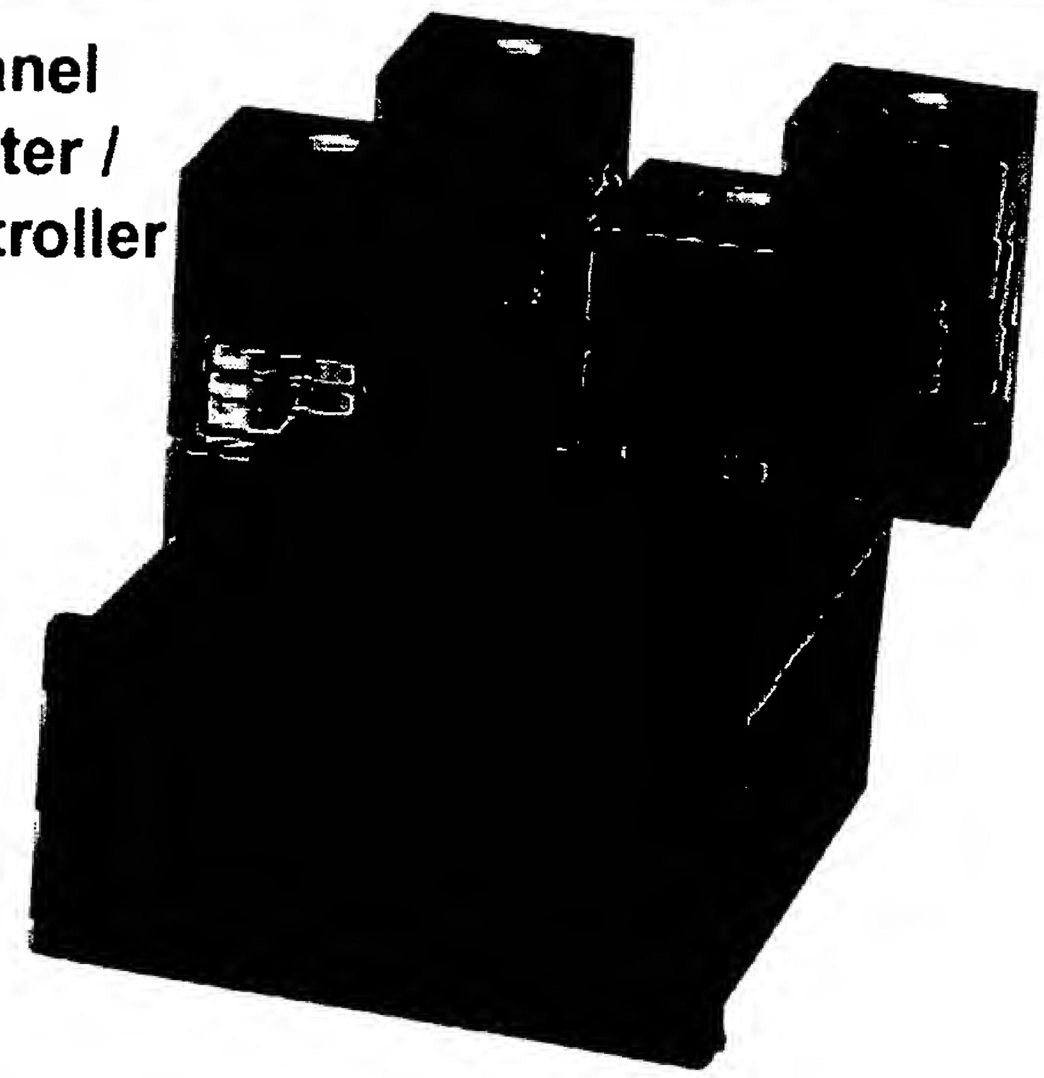
Standard Calibration- Compression

Capacity lbs	L	W	H	Thread	Model Number	
50	2	0.5	2.5	⅜ - 24	SB050	
100	2	0.5	2.5	⅜ - 24	SB0100	
200	2	0.5	2.5	⅜ - 24	SB0200	
300	2	0.5	2.5	⅜ - 24	SB0300	
500	2	1	3	½ - 20	SB0500	
750	2	1	3	½ - 20	SB0750	
1000	2	1	3	½ - 20	SB01K	
2000	2	1	3	½ - 20	SB02K	
3000	2	1	3	½ - 20	SB03K	
5000	2.5	1.5	3.5	¾ - 18	SB05K	

(Dimensions (in.): L, W, H, Thread)

* Add **-TC** as suffix to model number above for both tension and compression calibration add..........

Panel Meter / Controller



- **Use with single load cells or up to four cells wired in parallel for summing applications...great for tank level measurement where conventional level sensors won't work (e.g. powders, grains, dusty materials, etc...)**

√ Hopper / Bin / Tank weighing √ Web tension
√ Steel / Paper mills √ Electrohydraulic shaker systems

- **Provides excitation voltage for up to four load cells and with simple front panel push button setup can be scaled a full five digits from 0 to 99,999 t read directly in engineering units such as grams, ounces, pounds, gallons, tons, etc.**
- **Samples at 60 readings per second for fast c ntrol response, true peak reading capability, and an analog output (optional)**
- **Peak value can be displayed at the push of a button**
- **Auto tare allows the meter to be set to zero f r any input signal level...great for zeroing out tank / bin weight for true net product weight / level indication**
- **Worldwide input power: 85-264 VAC & 90-370 VDC**
- **Accuracy at 25°C: 0.01% FS ± 1 count**

Order load cells separately

Model Number	Description	
DPM3	Digital Panel Meter	
C	Dual Setpoint (Hi / Lo) Output Relays Form C (dry contacts), rated 10A @ 240 VAC	
H	Linear Analog Outputs 0 to 10 VDC, 0 to 20 mA and 4 to 20 mA	
T	Isolated Digital Communication RS-232 for interface and meter setup RS-485 to interface with multiple meters Parallel BCD o/p; 300 to 19,200 baud	
V	Optional low voltage input power 9 to 37 VDC and 8 to 28 VAC	

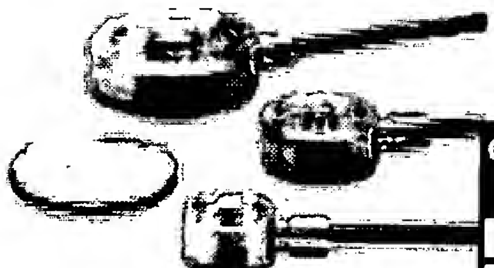
DPM3 - C - H - T - V Meter with all options.................
Meter may be ordered w/ any combination of available options

Load cells available for almost every application, different sizes and shapes, please call for a selection sheet

..............LOAD CELLS FOR ALMOST EVERY APPLICATION

(All load cells come complete with 10 ft cord and 9 pin connector installed)

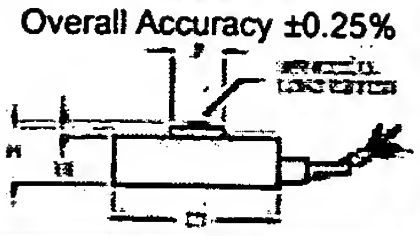
Compression-Only Load Buttons



Subminiatur

Great for limited space applications

Overall Accuracy ±0.25%



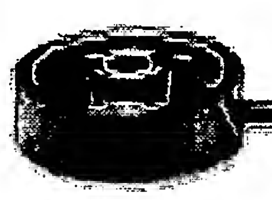
Capacity lbs	Dimensions (In.) D	D1	H	H1	Model Number
25	0.09	0.375	0.25	0.03	SLB25
50	0.09	0.375	0.25	0.03	SLB50
100	0.125	0.5	0.25	0.02	SLB100
250	0.125	0.5	0.25	0.02	SLB250
500	0.25	0.75	0.25	0.03	SLB500
750	0.25	0.75	0.25	0.03	SLB750
1,000	0.25	0.75	0.25	0.03	SLB1K

Low Profile

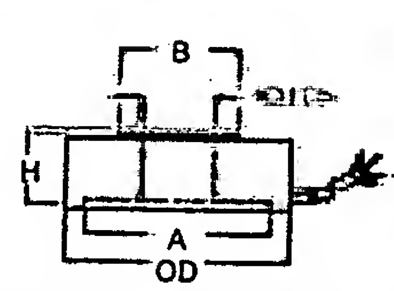
Capacity lbs	Dimensions (Inches) D Dia.	D1 Dia.	H	H1	A-Cap Screw	C-Bolt Screw	Model Number
100	0.32	1.24	0.4	0.07	#2	1	LBC100
250	0.32	1.24	0.4	0.07	#2	1	LBC250
500	0.32	1.24	0.4	0.07	#2	1	LBC500
750	0.32	1.24	0.4	0.07	#2	1	LBC750
1,000	0.32	1.24	0.4	0.07	#2	1	LBC1K
2,000	0.32	1.24	0.4	0.07	#2	1	LBC2K
3,000	0.45	1.49	0.62	0.08	#4	1.25	LBC3K
5,000	0.45	1.49	0.62	0.08	#4	1.25	LBC5K
10,000	0.45	1.49	0.62	0.08	#4	1.25	LBC10K
15,000	0.6	1.99	1	0.12	#6	1.625	LBC15K
20,000	0.6	1.99	1	0.12	#6	1.625	LBC20K
30,000	0.6	1.99	1	0.12	#6	1.625	LBC30K
50,000	0.8	2.99	1.5	0.18	#6	2.375	LBC50K

Compression-Only Through-Hole Load Cells

- Wide range and size selection...from 50 all the way up to 50,000 lbs
- Sealed for protection against most industrial environments
- Four physical sizes and up to nine different inside diameters to choose from • Overall Accuracy ±0.25%



Capacity lbs	Dimensions (In.) OD	H	A	B	Available Inside Hole dia.	Model Number
50	1	0.28	0.75	0.38	-P,-Q only	THA50
100						THA100
250						THA250
500						THA500
100	1.5	0.5	1.25	0.5	-P, -Q, -R, -S only	THB100
250						THB250
500						THB500
1,000						THB1K
2,000						THB2K
250	2	0.63	1.5	0.88	-P, -Q, -R, -S, -T, -V only	THC250
500						THC500
1,000						THC1K
2,000						THC2K
3,000						THC3K
5,000						THC5K
7,500						THC75K
10,000						THC10K
2,000	3	1	2.36	1.6	All	THD2K
3,000						THD3K
5,000						THD5K
7,500						THD75K
10,000						THD10K
15,000						THD15K
20,000						THD20K
30,000						THD30K
50,000						THD50K

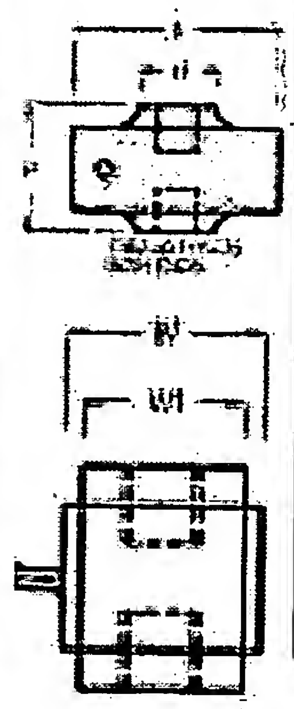


** Thru-hole diameter must be specified when ordering. Add suffix identifier listed below to desired load cell model number (must be compatible...see chart)

Inside Hole Diameter Identifiers (Must Choose One)	Add desired suffix to applicable model number above -P	-Q	-R	-S	-T	-V	-W	-Y	-Z
Nominal Hole Diameter	⅛"	3/16"	¼"	⅜"	½"	⅝"	¾"	1"	1¼"
Actual Hole Diameter	0.128	0.193	0.266	0.391	0.532	0.656	0.781	1.032	1.281

Mini Low Profile Load Cells

Universal Tension and / or Compression
Standard Calibration- Compression



±0.1% Accuracy

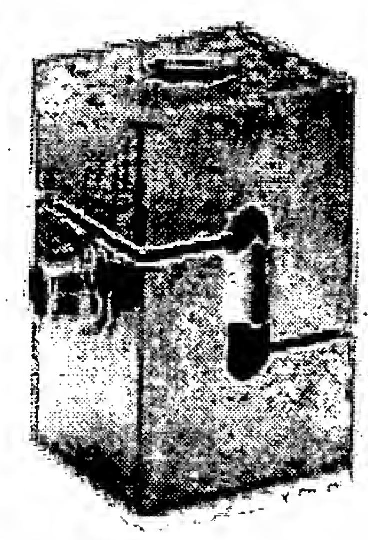
Capacity lbs	Dimensions (Inches) L	L1	W	W1	H	Thread	Model Number
10	1.504	0.6	0.54	0.375	0.75	10 - 32	MLP10
25	1.521	0.6	0.66	0.5	0.75	¼ - 28	MLP25
50	1.584	0.625	0.66	0.5	0.75	¼ - 28	MLP50
75	1.64	0.65	0.66	0.5	0.75	¼ - 28	MLP75
100	1.664	0.66	0.66	0.5	0.75	¼ - 28	MLP100
150	1.642	0.575	0.93	0.75	1	⅜ - 24	MLP150
200	1.688	0.58	0.93	0.75	1	⅜ - 24	MLP200
300	1.748	0.6	0.93	0.75	1	⅜ - 24	MLP300
500	1.658	0.58	0.93	0.75	1	⅜ - 24	MLP500
750	1.734	0.585	0.93	0.75	1	⅜ - 24	MLP750
1000	1.784	0.615	0.93	0.75	1	⅜ - 24	MLP1K

* Add -TC as suffix to Model Number above for both Tension and Compression Calibration..........

Hermetically-Sealed Tension* or Compression Load Cells

...great for harsh industrial environments, especially food manufacturing, requiring frequent washdown

Standard Calibration- Compression

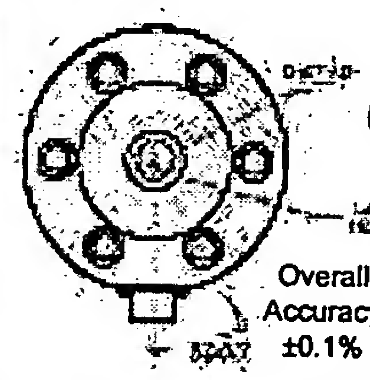


Overall Accuracy ±0.1%

Capacity lbs	Dimensions (In.) H	W (sq)	Thread	Model Number
1,000	2.5	1.425	⅜-24 UNF	HSW1K
2,000	2.5	1.425	⅜-24 UNF	HSW2K
3,000	2.5	1.425	½-20 UNF	HSW3K
5,000	3	1.925	⅝-16 UNF	HSW5K
10,000	3	1.925	⅝-16 UNF	HSW10K
20,000	4	2.900	1-14 UNS	HSW20K
30,000	5.25	2.900	1¼-12 UNF	HSW30K
50,000	6.25	2.900	1½-12 UNF	HSW50K

* Add -TC as suffix to Model Number above for both Tension & Compression Calibration...

Universal Tension* or Compression "Pancake" Cells

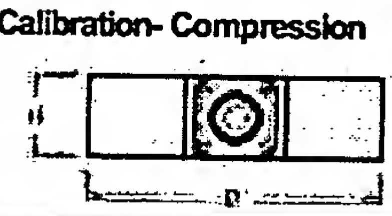


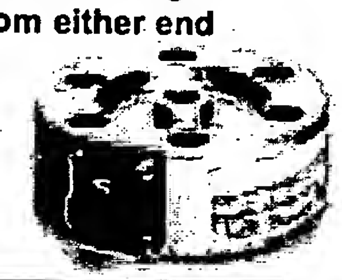
Overall Accuracy ±0.1%

Hold down bolt holes are provided through the outer diameter and a threaded hole provided through the center for pushing or pulling from either end

Standard Calibration- Compression

F Clearance holes eq space on G dia Bolt Circle. K Bolt Holes are counter bored for ranges -15K & below





Capacity lbs	Dimensions (Inches) D	H	F	G	K	J	Center Thread	Model Number
100	3	1	6	2.25	0.28	0.625	⅜-24 UNF	LPU100
250	3	1	8	2.25	0.28	0.625	⅜-24 UNF	LPU250
500	3	1	6	2.25	0.28	0.625	⅜-24 UNF	LPU500
1,000	3	1	6	2.25	0.28	0.625	⅜-24 UNF	LPU1K
2,000	3.5	1	6	2.63	0.34	0.775	½-20 UNF	LPU2K
3,000	3.5	1	6	2.63	0.34	0.775	½-20 UNF	LPU3K
4,000	3.5	1	6	2.63	0.34	0.775	½-20 UNF	LPU4K
5,000	3.5	1	6	2.63	0.34	0.775	½-20 UNF	LPU5K
7,500	5.5	1.8	8	4.5	0.41	1.75	1-14 UNS	LPU75K
10,000	5.5	1.8	8	4.5	0.41	1.75	1-14 UNS	LPU10K
15,000	5.5	1.8	8	4.5	0.41	1.75	1-14 UNS	LPU15K
20,000	6	1.8	8	4.88	0.53	2.125	1½-12 UNF	LPU20K
30,000	6	1.8	8	4.88	0.53	2.125	1½-12 UNF	LPU30K
50,000	6	1.8	8	4.88	0.53	2.125	1½-12 UNF	LPU50K

* Add -TC as suffix to Model Number above for both Tension and Compression Calibration..

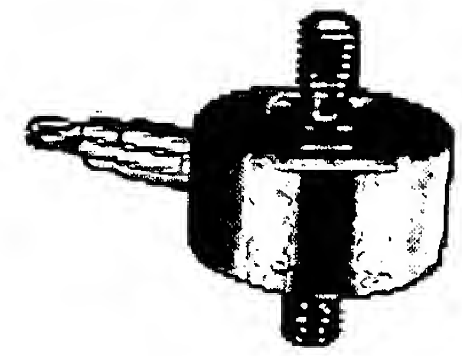
Precision Miniature Load Cells

Model 31 and 34

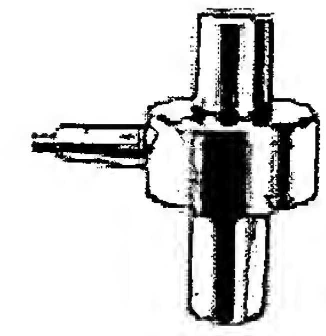
WELDED STAINLESS

RUGGED, SMALL SIZE

TENSION/COMPRESSION



Model 31
(Tension/Compression)



Model 34
(Tension/Compression)

Models 31 and 34, Precision Miniature load cells measure both tension and compression load forces of 50 grams to 10,000 lbs. These models are our highest accuracy, rugged miniature load cells. Model 31's welded, stainless steel construction is designed to eliminate or reduce to a minimum, the effects of off-axis loads. (The internal construction assures excellent long term stability for ranges 1000 grams and above.) A modification permits this model to be completely welded for underwater applications. The Model 31 tension/compression load cell has male threads while the Model 34 tension/compression load cell has female threaded load attachments. High accuracies of 0.15-0.25% full scale are achieved. Each bonded strain gage unit is built of welded 17-4 PH stainless steel for additional ruggedness. All load cells that have ranges ≤10 lbs. have a small electrical zero balance circuit board which is in the lead wire (approximately 1"x .087" thick). This balance board does not have to be the same temperature as the transducer. Applications include cable tension and electromechanical parts testing.

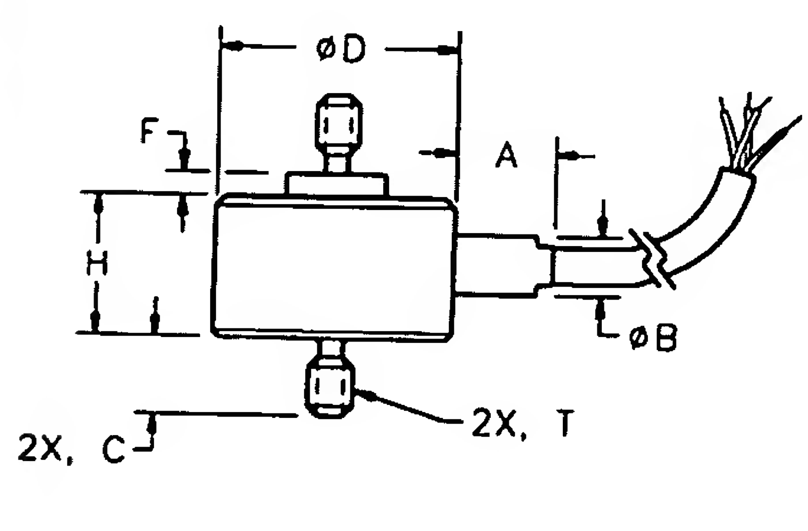
Dimensions

Model 31 (Order Code AL311)

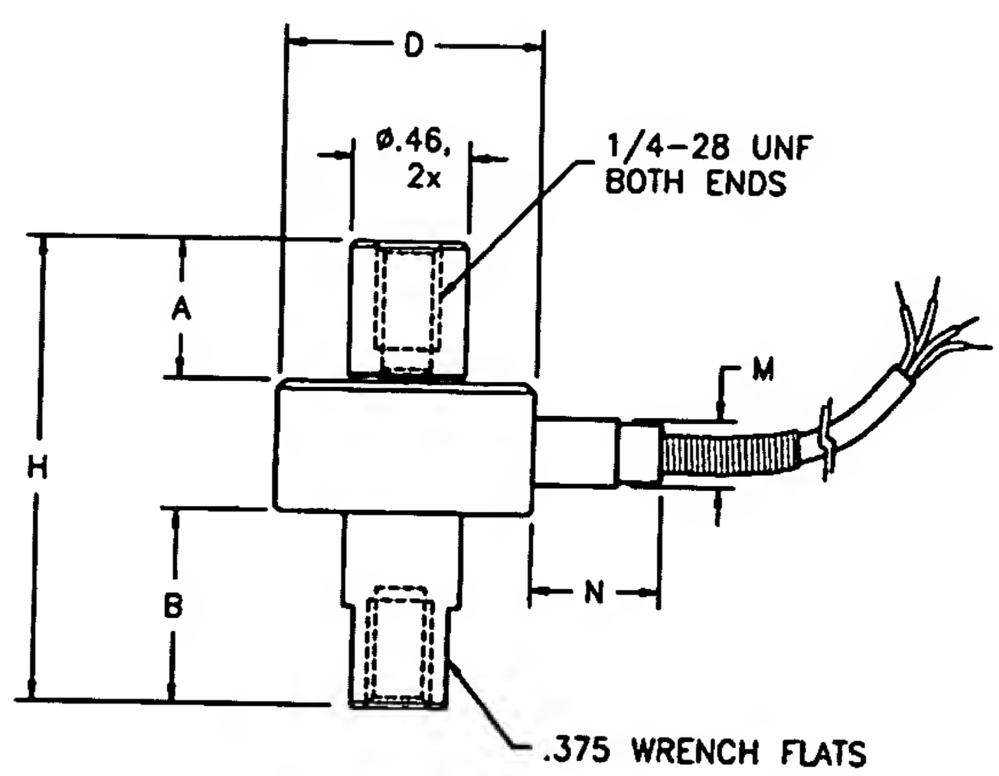
Available Ranges*	T Thread	D"	H"	C"	F"	A"	B"
50; 150; **250** 500; gm.	#6-32 UNC	1.00	.75	.25	.11	.50	.38
1000 gm.; 5; 10 lbs.	#6-32 UNC	.75	.45	.25	.05	.31	.19
25; 50; 100 lbs.	#10-32 UNF	1.00	.52	.25	.03	.50	.25
250; 500; 1000 lbs.	¼-28 UNF	1.00	.52	.38	.03	.50	.25
2000; 3000 lbs.	⅜-24 UNF	1.00	.72	.50	.03	.50	.38
4000; 5000 lbs.	½-20 UNF	1.25	.94	.63	.03	.50	.38
7500; 10,000 lbs.	¾-16 UNF	1.38	1.10	.88	.03	.50	.38

* Stocked ranges are in bold face print.

Notes: Model 31 load cells ≤ 250 grams have overload stops. For custom cells without overload stops consult SENSOTEC.



Model 31 Male Threads
(Tension/Compression)



Model 34 Female Threads
(Tension/Compression)

Model 34 (Order Code AL312)

Available Ranges	D"	H"	A"	B"	M"	N"
50; 150; 250; 500 gm.	1.00	1.75	.52	.52	.38	.50
1000 gm.; 5; 10 lbs.	.75	1.75	.60	.72	.19	.31
25; 50; 100 lbs.	1.00	1.75	.52	.72	.25	.50
250; 500; 1000 lbs.	1.00	2.00	.75	.75	.25	.50

Options (See Appendix)

Temperatur compensated 1b, 1c, 1f; Special calibration 30a, 30b
Premium Opti ns: 1d, 1e, 1g, 1h (≥25 lb), 1i; 6d; 9a (≥5 lb.)
Accessories: Rod end attachments for Model 31

		Model 31 (Male Threads) (Tension/Compression) Order Code AL311	**Model 34** (Female Threads) (Tension/Compressi n) Order Code AL312
PERFORMANCE	Load Ranges	50 gms to 10,000 lbs.	50 gms to 1,000 lbs.
	Non-Linearity/Hysteresis (max)		
	50 gms to 1000 gms	±0.15% F.S.	±0.15% F.S.
	5 to 250 lbs	±0.15% F.S.	±0.15% F.S.
	500 to 10,000 lbs	±0.2% F.S.	±0.2% F.S.
	Non-Repeatability (max)		
	50 gms to 1000 gms	±0.1% F.S.	±0.1% F.S.
	5 to 10,000 lbs	±0.05% F.S.	±0.05% F.S.
	Output (standard)		
	50 to 150 gms (semi)	.1mV/V/gm max	.1mV/V/gm
	250 to 500 gms (semi)	20mV/V	20mV/V
	1000 gms	1.5mV/V (nominal)	1.5mV/V (nom)
	5 lbs. to 10,000 lbs. (foil)	2mV/V	2mV/V
	Resolution	Infinite	Infinite
ENVIRONMENTAL	Temperature, Operating	-65° F to 250° F	-65° F to 250° F
	Temperature, Compensated	60° F to 160° F	60° F to 160° F
	Temperature Effect – Zero/Span (max)		
	50 gms to 500 gms	.015% F.S./° F	.015% F.S./° F
	1000 gms	.005% F.S./° F	.005% F.S./° F
	5 to 10,000 lbs	.005% F.S./° F	.005% F.S./° F
ELECTRICAL	Strain Gage Type	Foil or Semiconductor	Foil or Semiconductor
	Excitation (Calibration)		
	50 gms to 10 lbs	5.00VDC	5.00VDC
	20 lbs. to 10,000 lbs	10.0VDC	10.0VDC
	Insulation Resistance	5000 megohm @ 50VDC	5000 megohm @ 50VDC
	Bridge Resistance		
	50 gms to 500 gms	500 ohm (semi)	500 ohm (semi)
	1000 gms	350 ohm (foil)	350 ohm (foil)
	5 to 10,000 lbs	350 ohm (foil)	350 ohm (foil)
	Shunt Calibration Data	Included	Included
	Wiring Code (std)	#1 (See Pg. AP-8)	#1 (See Pg. AP-8)
	Electrical Termination (std)	Teflon cable (5 ft.)	Teflon cable (5 ft.)
MECHANICAL	Overload, Safe	50% over capacity	50% over capacity
	Thread Size	See table	See table
	Deflection – Full Scale	.0005"-.0020"	.0005"-.0020"
	Casing material	17-4 PH Stainless	17-4 PH Stainless
	Weight (nom)	1.6 oz.	2.5 oz.
IN-LINE AMPLIFIERS (Optional)	Outputs Available	±5VDC, 4-20mA	±5VDC, 4-20mA

NOTES *Standard calibration for tension/compression load cells is in tension only.

General Information

How to order (See Pg. AP-19)
Load cell selection flow chart (See Pg. LO-1)
Installation Note: Maximum torque for installation of Model 31 in ranges less than 25 lbs. is 12 inch lbs.

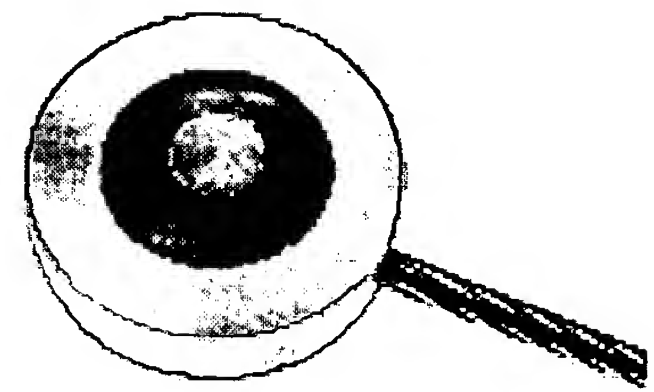
Low Cost Load Cell

Model 53

±0.25% NON-LINEARITY

5 TO 50,000 LBS.

STAINLESS STEEL

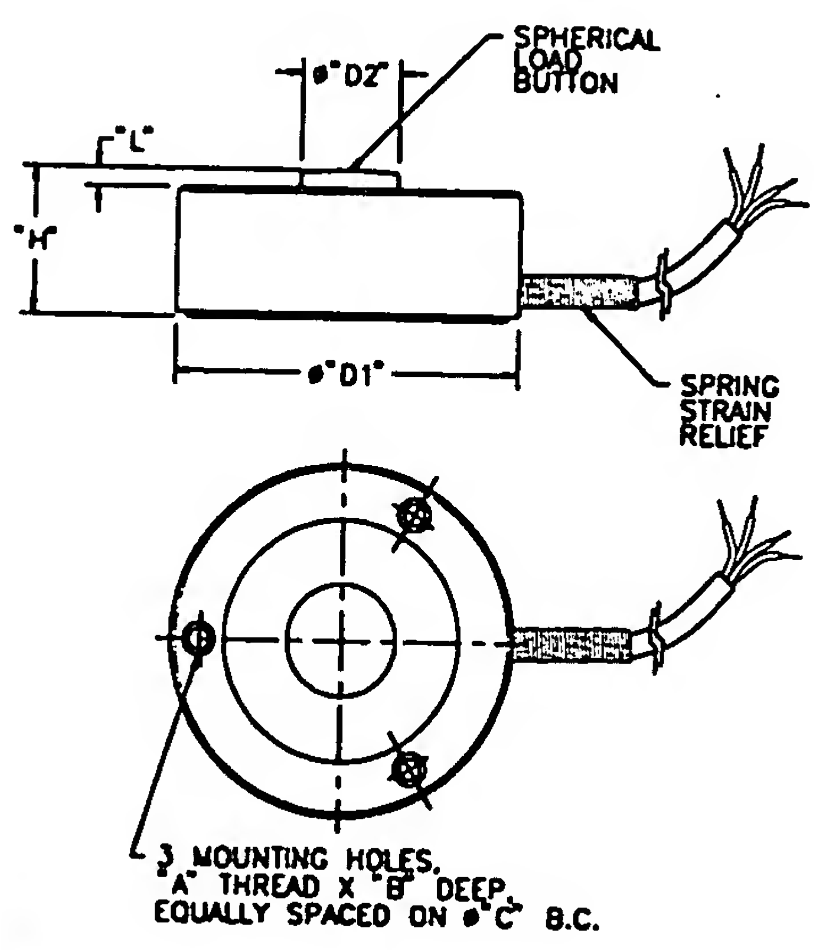


Model 53 load cells are bonded foil strain gage transducers designed for low cost production and testing applications (i.e. press calibration). Engineered compression force measurements up to 50,000 lbs., this model achieves a maximum non-linearity of 0.25% full scale. Precision gaging techniques and a stainless steel construction provides excellent long-term stability and reliability under severe operating conditions. The Model 53 compression-only load cell has an integral load button machined as part of the load cell. The Model 53 must be mounted on a smooth flat surface for proper operation. Three tapped holes are provided for mounting.

Dimensions

(Order Code) AL131)

Ranges	D1"	D2"	H"	L"	A"	B"	C"
5, 10, 25, 50, 100 lbs.	1.00	.21	.62	.05	#4-40 UNC	.22	.75
250, **500**, **1000**, **2000** lbs.	1.25	.32	.39	.07	#6-32-UNC	.25	1.00
3000, 4000, **5000**, 7500, **10,000** lbs.	1.50	.43	.63	.08	#6-32 UNC	.25	1.25
15,000, **20,000**, 30,000 lbs.	2.00	.60	1.00	.12	#6-32 UNC	.25	1.625
50,000 lbs.	3.00	.78	1.50	.18	#6-32 UNC	.25	2.375



Options (See Appendix)

Temperature compensated 1b; 1c; 1e

Premium Options: 1g; 1h; 1i; 6d; 6i (H" dimension will increase); 12b

Model 53
(Compression Only)
Order Code AL131)

		Model 53 (Compression Only) Order Code AL131)
PERFORMANCE	Load Ranges	5 to 50,000 lbs.
	Non-Linearity (max)	±0.25% F.S.
	Hyster sis (max)	±0.3% F.S.
	Non-Repeatability (max)	±0.1% F.S.
	Output (standard)	2mV/V
	Resolution	Infinite
ENVIRONMENTAL	Temperature, Operating	-65° F to 250° F
	Temperature, Compensated	60° F to 160° F
	Temperature Effect	
	– Zero (max)	.005% F.S./° F
	– Span (max)	.01% Rdg./° F
ELECTRICAL	Strain Gage Type	Bonded foil
	Excitation (calibration)	10VDC
	Excitation (acceptable)	Up to 10VDC or AC
	Insulation Resistance	5000 megohm @ 50VDC
	Bridge Resistance	350 ohms
	Shunt Calibration Data	Included
	Wiring Code (std.)	#1 (See Pg. AP-8)
	Electrical Termination (std)	Teflon cable (5 ft.)
MECHANICAL	Overload, Safe	50% over capacity
	Deflection – Full Scale	.001" – .003"
	Casing Material	17-4 PH Stainless
IN-LINE AMPLIFIERS (Optional)	Outputs Available	0-5VDC, 4-20mA

General Information

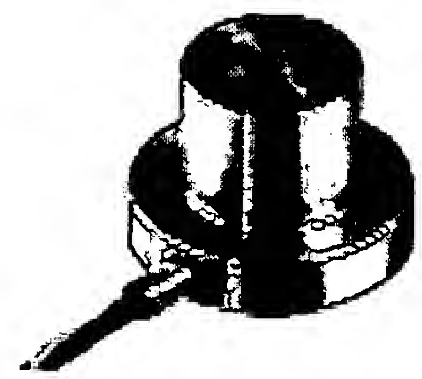
How to order (See Pg. AP-19)
Load cell selection flow chart (See Pg. LO-1)

Subminiature Load Cells

Mod l LFH-7I (Top Hat)

250-10,000 LBS

STAINLESS STEEL



Model LFH-7I
Compression Only

Model LFH-7I Subminiature Load Cell is a low profile force transducer for applications with minimal space and high capacity requirements. This transducer utilizes foil strain gages to measure compression loads of up to 10,000 lbs. and achieves non-linearity and hysteresis of +/- 0.5% full scale. The top of the load cell is the area where the force is applied and the base ring of the load cell must be placed on a hard, machine-ground flat surface to obtain optimum accuracy.

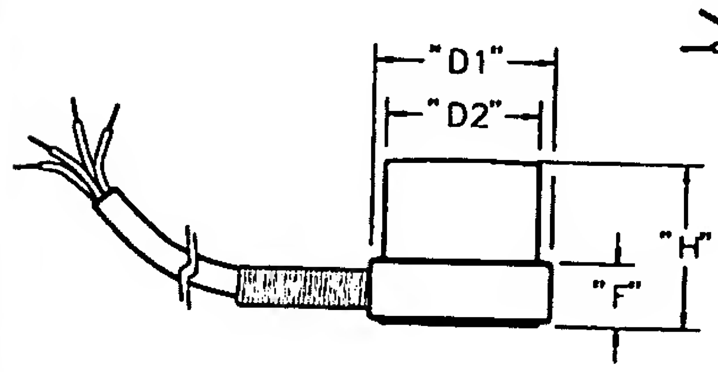
SPECIFICATIONS

	Model LFH-7I (Compression Only) Order Code BL351
Load Ranges	250 to 10,000 lbs.
Overall Accuracy	±0.7% F.S.
Output	1.5mV/V-2.5mV/V
Temperature, Operating	-65° F to 250° F
Temperature, Compensated	60° F to 160° F
Temperature Effect	
– Zero (max)	.01% F.S./° F
– Span (max)	.01% Rdg./° F
Excitation (calibrated)	5VDC
Bridge Resistance	350 ohms
Wiring Code (std)	#1 (See Pg. AP-8)
Electrical	
Termination (std)	Cable (5 ft.)
Overload, Safe	50% over capacity
Deflection—Full Scale	.001"-.003"

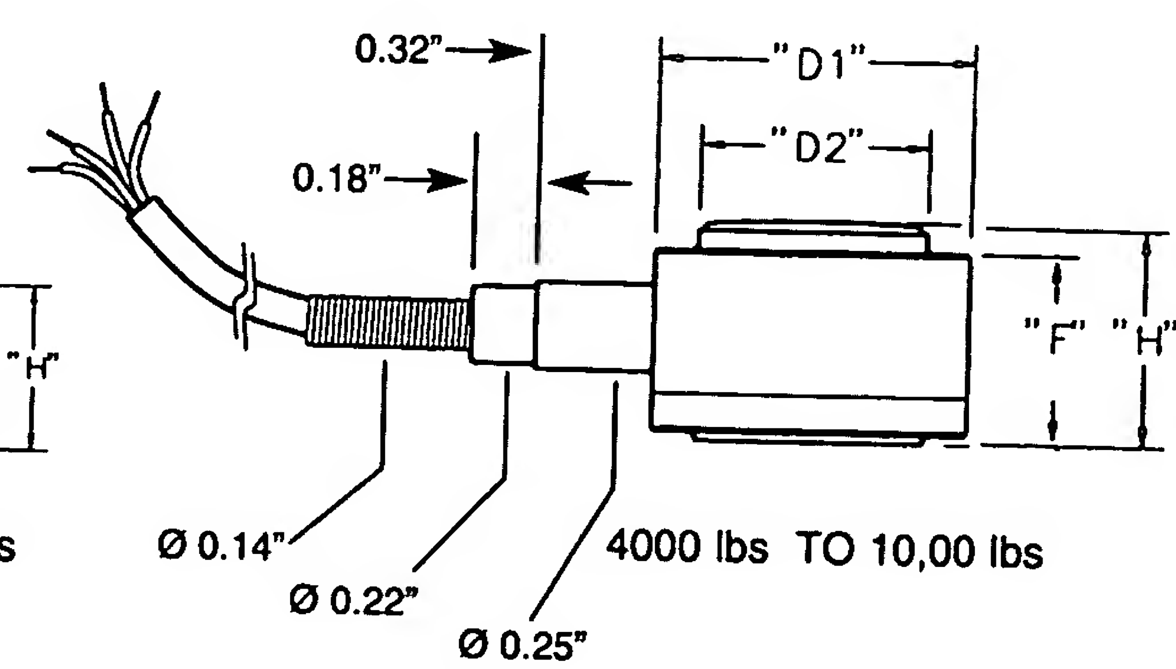
Dimensions

Top Hat Model LFH-7I (Order Code BL351)

Available Ranges	D1" Dia.	D2" Dia.	H"	F"
250 lbs.	.50 (1.27 cm)	.22 (.69 cm)	.38 (.97 cm)	.13 (.33 cm)
500 lbs.	.50 (1.27 cm)	.28 (.71 cm)	.38 (.97 cm)	.13 (.33 cm)
1000 lbs.	.50 (1.27 cm)	.31 (.79 cm)	.38 (.97 cm)	.13 (.33 cm)
2000 lbs.	.50 (1.27 cm)	.41 (1.04 cm)	.38 (.97 cm)	.13 (.33 cm)
3000 lbs.	.50 (1.27 cm)	.45 (1.14 cm)	.38 (.97 cm)	.13 (.33 cm)
4000 lbs.	.63 (1.60 cm)	.49 (1.24 cm)	.60 (1.52 cm)	.23 (.58 cm)
5000 lbs.	.63 (1.60 cm)	.53 (1.35 cm)	.60 (1.52 cm)	.23 (.58 cm)
7500 lbs.	.88 (2.24 cm)	.63 (1.60 cm)	.63 (1.60 cm)	.54 (1.37 cm)
10,000 lbs.	.88 (2.24 cm)	.63 (1.60 cm)	.63 (1.60 cm)	.54 (1.37 cm)



250 lbs TO 3000 lbs

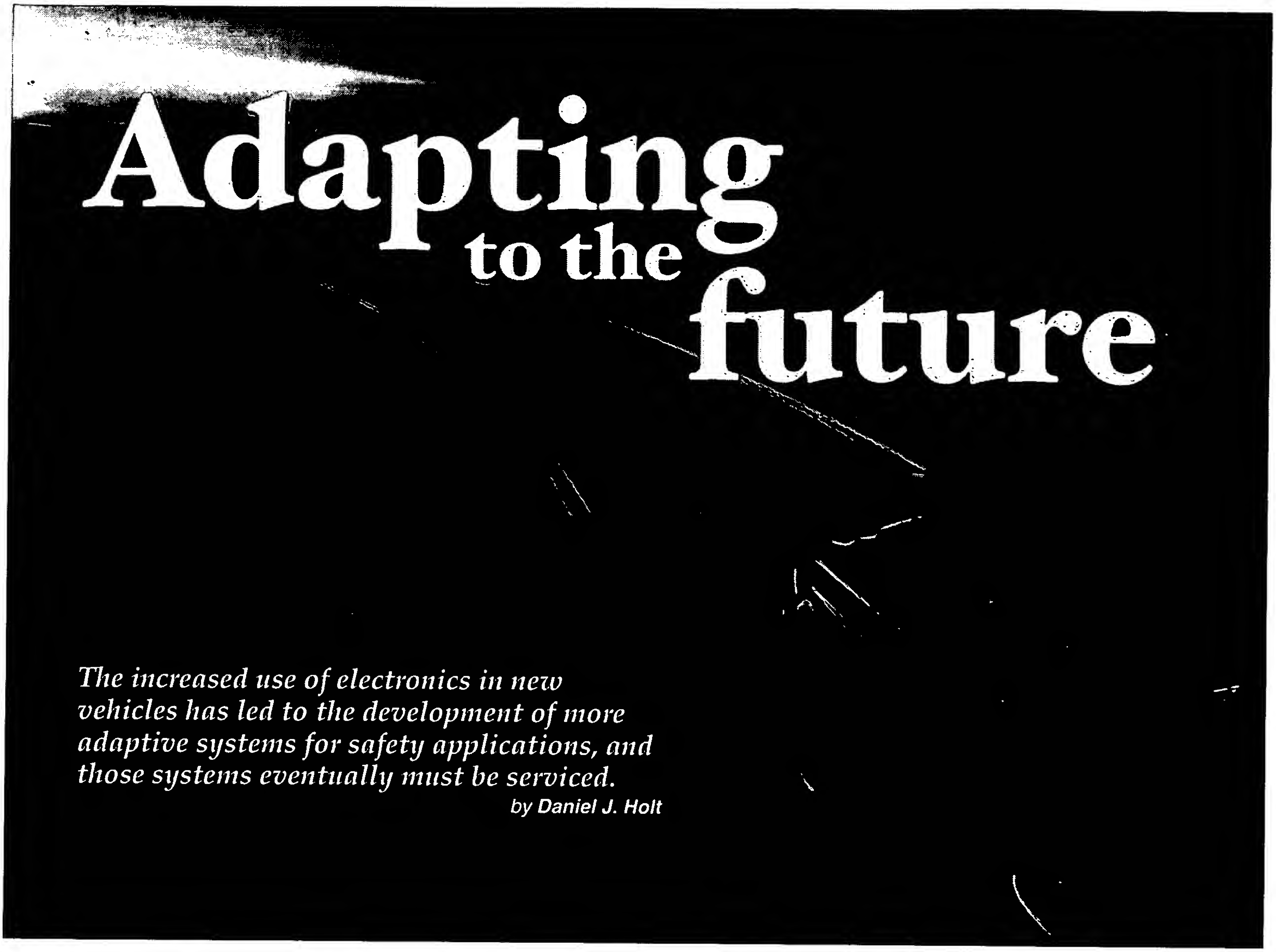


4000 lbs TO 10,00 lbs

Options (See Appendix)

Temperature compensated 1b, 1f

* Bridge resistance is 700 ohms on ranges > 5000 lbs.



Adapting to the future

The increased use of electronics in new vehicles has led to the development of more adaptive systems for safety applications, and those systems eventually must be serviced.

by Daniel J. Holt

The term "adaptive" is becoming more common when talking about today's vehicle systems. The increased use of electronics has allowed vehicle designers to tailor some systems or functions to a variety of drivers and conditions. Many of these adaptive systems are being developed to make vehicles safer and help drivers avoid accidents, or at least minimize their injuries.

When automobiles were first developed, the steering column was a solid rod with a steering wheel on one end and a connection to the steering gear on the other. In the case of certain frontal crashes, the steering column impaled the driver. In the 1960s, the collapsible steering column was developed; allowing the column to shorten on impact saved many lives.

Today, companies such as **Delphi** Corp. have developed an adaptive energy-absorbing steering column (Figure 1), which improves crashworthiness by adjusting the energy absorption levels based on factors such as occupant mass, seatbelt usage, seat position, vehicle speed, and crash severity. For this steering column to work efficiently, data must be transmitted to the electronic control unit from sensors that determine the above-mentioned factors.

Adaptive cruis ontr l

Cruise control can be a valuable asset on a long trip; however, today's technology acts more like a steady throttle control with no intelligence. Adaptive cruise control (ACC) is the first of many driver assistance programs that are being developed to minimize the risk and consequences of accidents and to increase the driving comfort level. An ACC system can reduce the number of rear-end collisions that can be caused by driver inattention and following too closely. Basically, ACC automatically adjusts vehicle speed to maintain a driver-specified adjustable distance behind a lead vehicle (Figure 2).

The ACC uses a forward-looking detection sensor that can either be laser- or radar-based to monitor the traffic in front of the ACC-equipped vehicle. The sensor assesses the distance, angular position, and relative speed of possible targets. If the

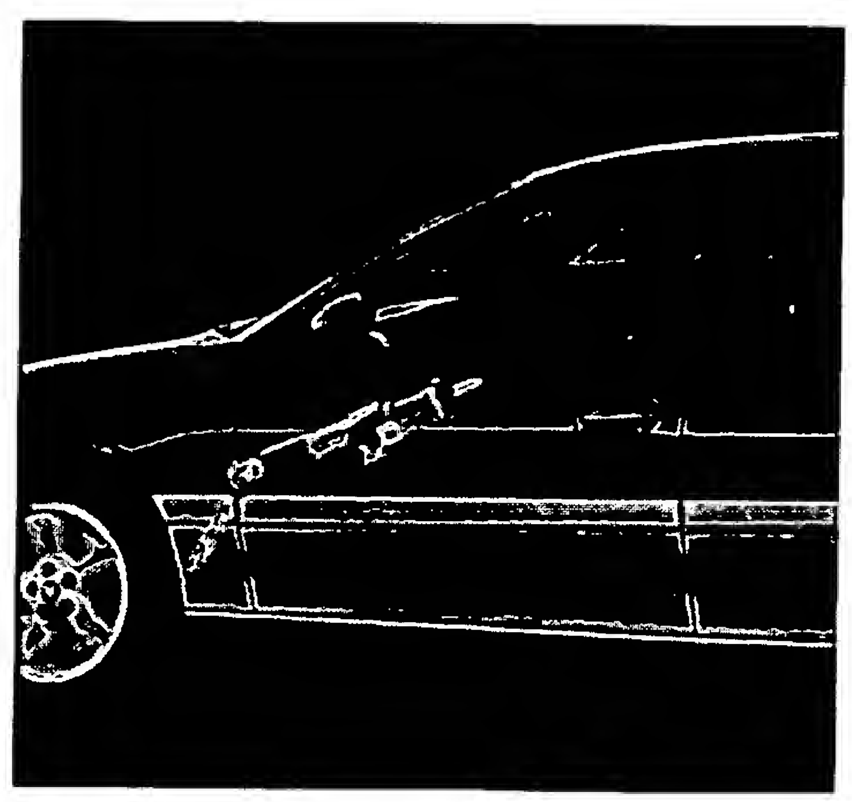


Figure 1. Delphi's adaptive energy-absorbing steering column improves crashworthiness by adjusting energy absorption levels based on factors such as seat position, vehicle speed, and crash severity.

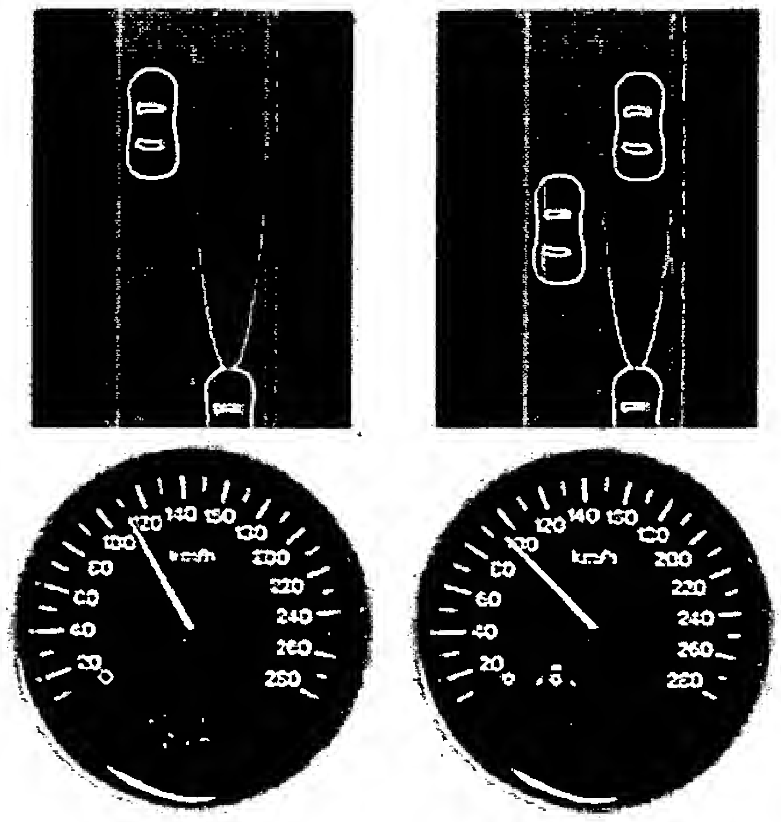


Figure 2. Delphi's adaptive cruise control system can detect objects up to 150 m (490 ft) and can be used effectively at speeds as low as 20 mph (32 km/h).

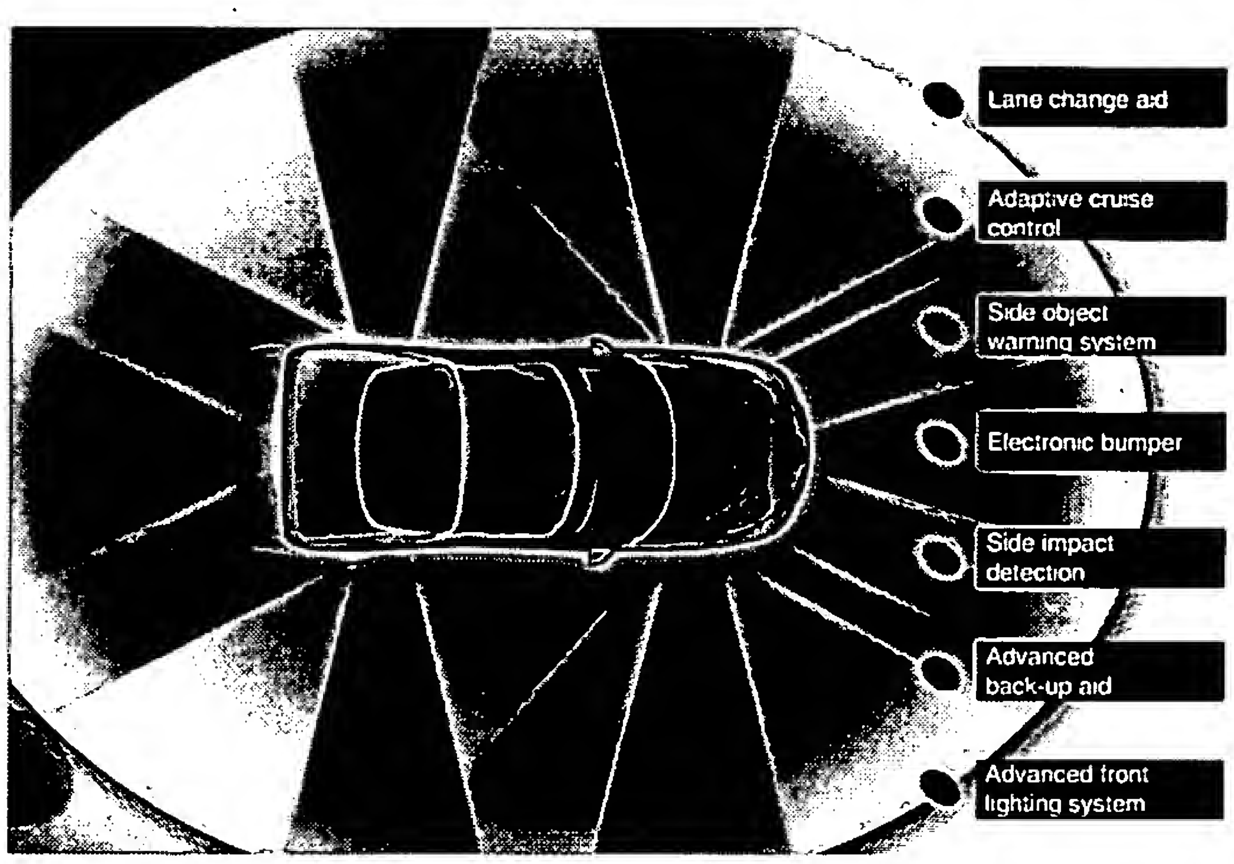


Figure 3. Visteon's "cocoon" system may eventually create an electronic barrier around a vehicle to protect it and its occupants.

sensor does not detect any objects, the vehicle maintains the driver's chosen speed just as in a standard cruise control. If an obstacle is detected, a safe distance is maintained by applying the brakes or reducing the engine speed by cutting back on the throttle. The driver still remains fully responsible for operating the car if emergency braking is required.

Some of the ACC systems have been developed with a stop-and-go capability. With this feature, the ACC stops the host vehicle as long as the vehicle it has targeted is stopped. The driver of the ACC-equipped vehicle starts off from a stationary state in the same manner as with a conventional vehicle. Stepping on the accelerator pedal deactivates the stop control.

Future enhancements that are being examined include:

• *Curve assistant*—Curves can be identified via the navigation system, and vehicle speed can be adjusted prior to entering the curve. A vision system can also be used to improve the detection of the road course.

• *Speed limit assistant*—Vision systems with image processing can detect traffic signs and road conditions. With this system, a driver can choose to allow the vehicle to control the maximum speed based on the posted speed limits.

• *Blind spot detection*—Changing lanes can be a dangerous maneuver if the driver does not check the blind spot. Systems are being developed that monitor the blind spot to detect overtaking vehicles approaching from the rear and the sides of the vehicle. Radar, lasers, and vision systems with image processing are being considered for this application.

• *Lane detection*—The detection of lane borders can help the driver with lane keeping. By controlling the lateral vehicle position electronically, the driver can concentrate more on traffic management and changing conditions. Notification can be given to the driver through steering-wheel feedback or audible warnings. When full steer-by-wire is developed, the vehicle can electronically be kept in the proper lane.

• *Automatic braking*—Systems are being developed that apply the brakes faster than a driver could once an emergency system has been detected. Sensors are needed to detect the position, contour, and relative speed of possible obstacles. The braking system is "pre-charged" in anticipation of an impending emergency situation. Variations on this system exist, but the goal is to apply the braking system with maximum force if the collision is unavoidable.

Many of these systems are being developed for **Visteon**'s electronic "Cocoon" (Figure 3) that may eventually create an electronic barrier around a vehicle to protect it.

With all this information available to the driver, new head-up displays (HUDs) are being developed so that the driver does not have to take his or her eyes from the road to obtain information. The chosen information is displayed to the driver as if it were hanging in front of the windshield. Figure 4 shows an advanced HUD being developed by **Siemens**. Night vision systems also use a type of HUD to display the view on the windshield.

Adaptive lighting and restraints

One of the first attempts to achieve adaptive lighting was on the 1948 Tucker that was equipped with three headlamps. The third headlamp, located in the center of the vehicle's front, moved in conjunction with the turning angle of the wheels. Today, adaptive

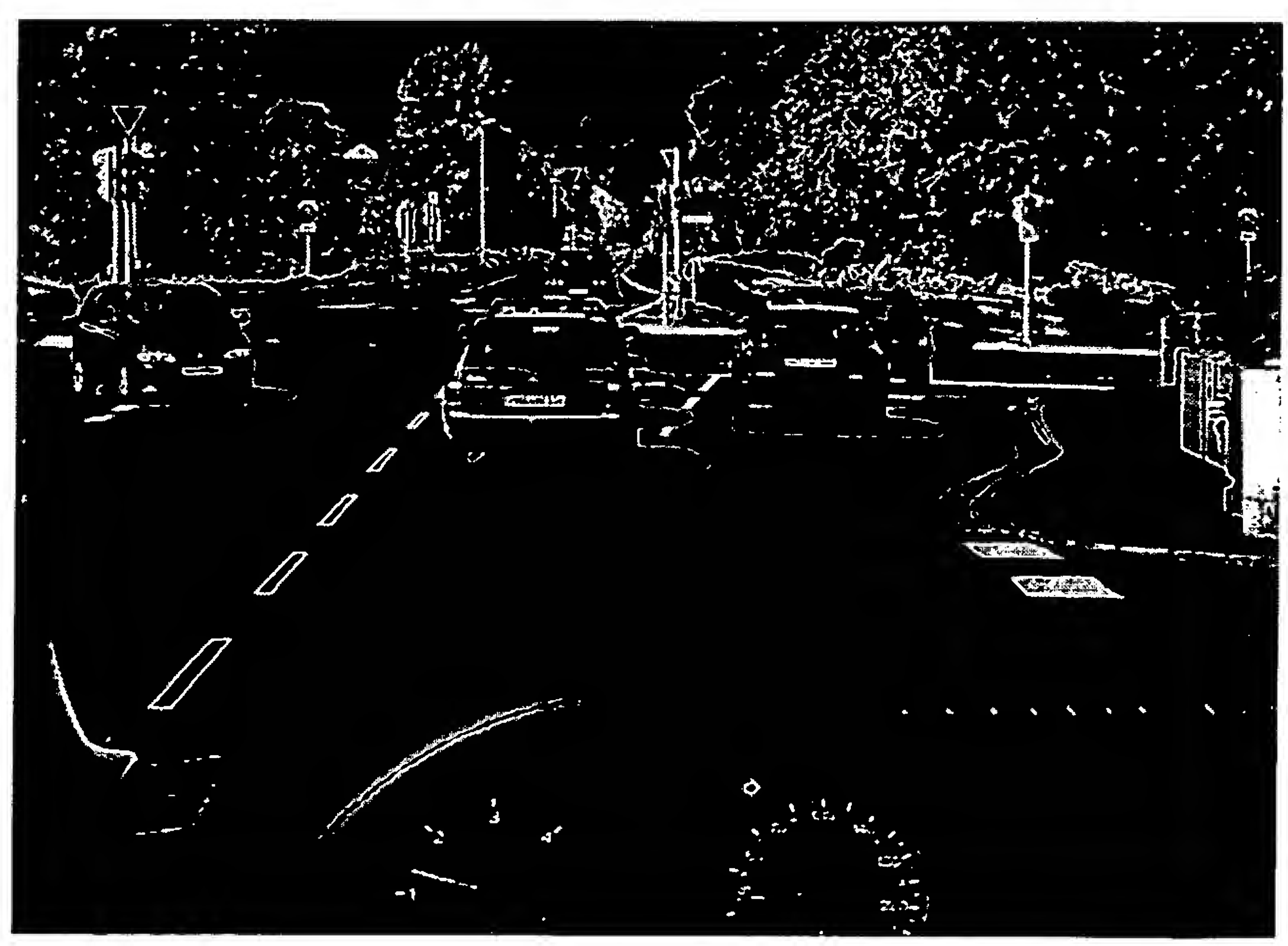


Figure 4. Head-up displays, such as Siemens' advanced HUD system, are being developed so that the driver does not have to take his or her eyes from the road to obtain information.

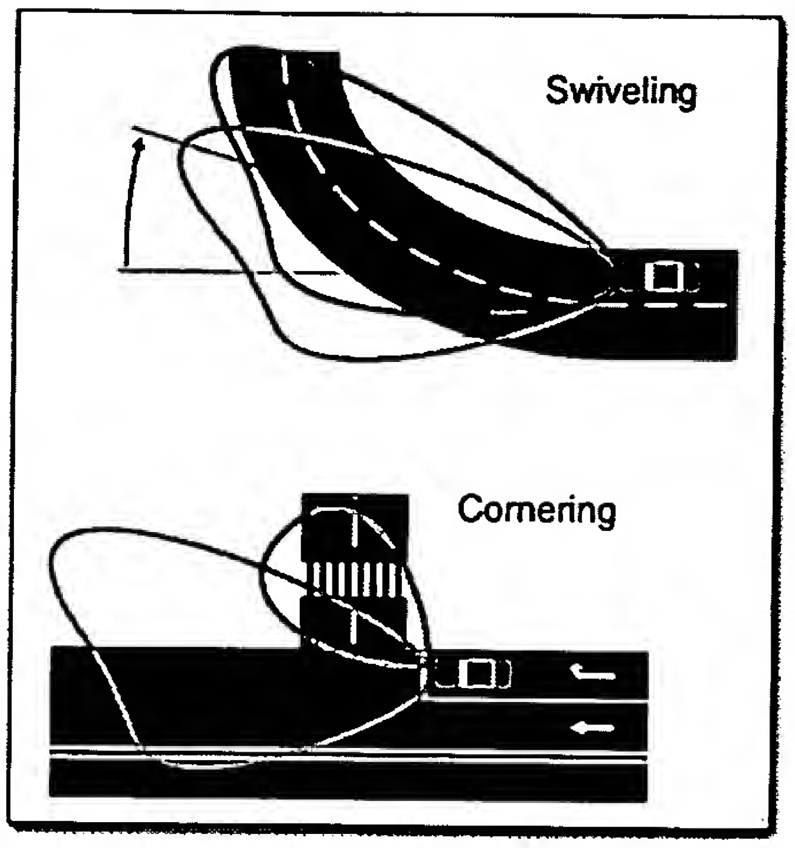


Figure 5. Visteon is researching an adaptive lighting system that illuminates impending curves and turns.

systems are again being investigated to illuminate curves ahead of the vehicle. Figure 5 shows the lighting patterns of an adaptive lighting system being researched by Visteon.

With today's systems, car specific information such as yaw rate, lateral acceleration, steering wheel angle, and/or wheel angle are required. This information can be used to control stepper motors that move the lights to illuminate the curves. Navigation and video systems can also supply data to the lighting system. Various systems can adjust the intensity of the lights and thereby the lighting ranges to meet the needs of the driver, depending on where the vehicle is being driven. Highway or interstate driving at high speeds may require a higher intensity light than city driving.

The overwhelming success of safety belts and airbags as restraint systems also has brought about the need to adapt these systems to driver size, weight, and seat position. Seatbelt tensioners and other devices control the rate at which the seatbelt can be unrolled or how it reacts in a crash situation. Much attention has been given to detecting the presence and size of passengers. This is especially true in detecting children in the front seat. Seatbelt force detection systems can also be used along with weight sensors (Figure 6).

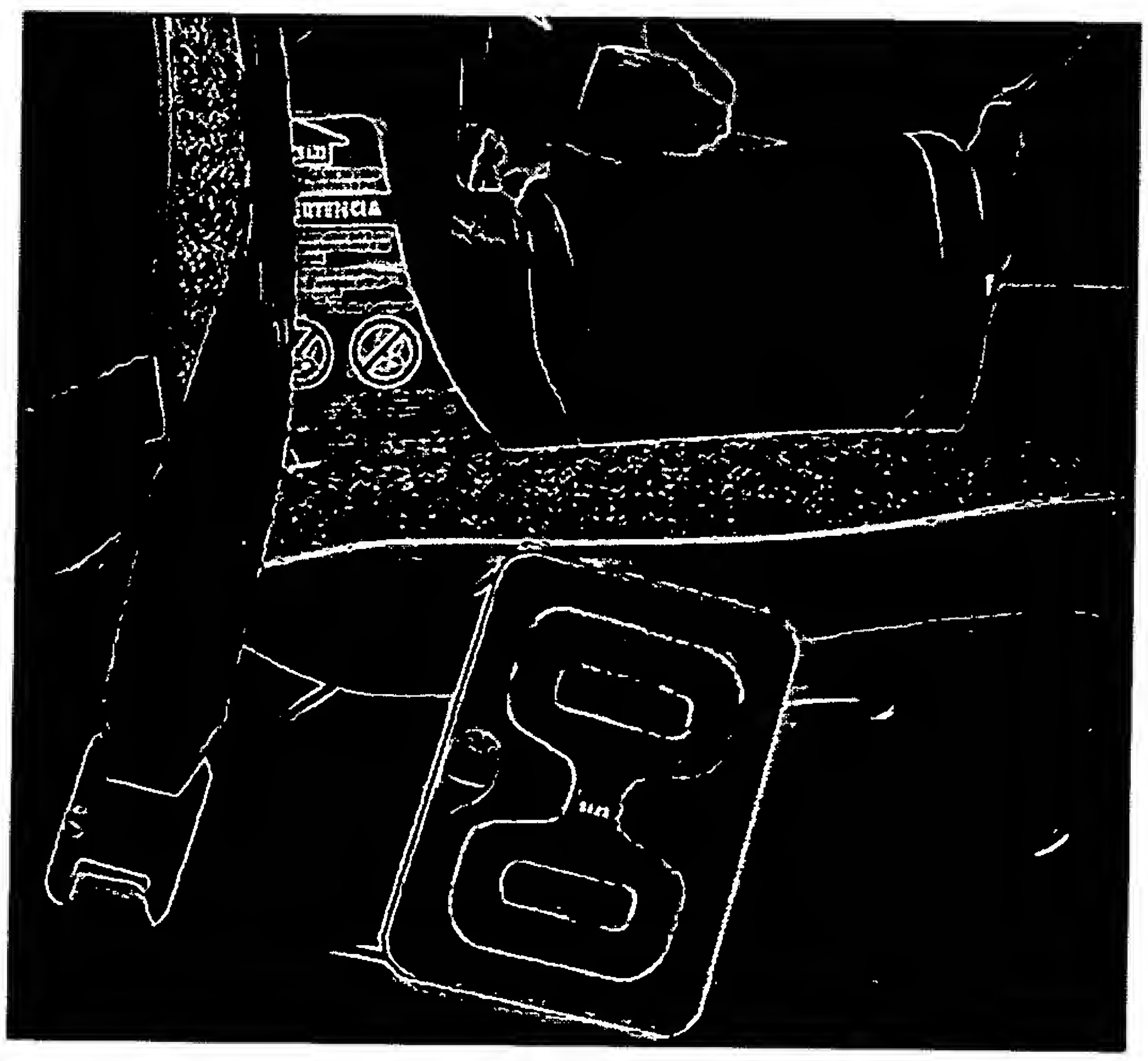


Figure 6. Siemens has developed an occupant weight classification system that employs strain gauge sensing in the seatbelt to measure the microstrains of force applied when an infant seat is used.

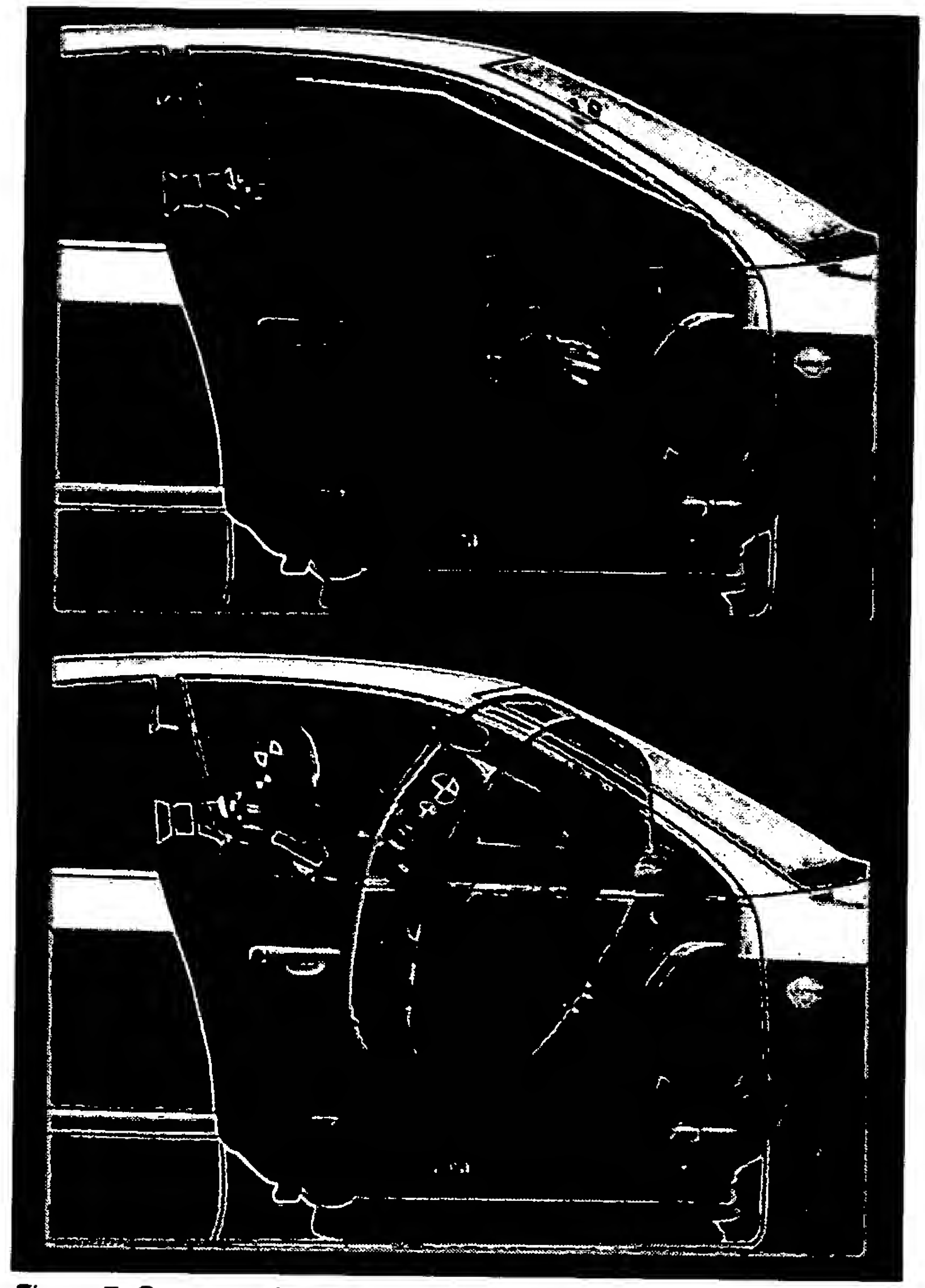


Figure 7. Occupant detection is used to determine if the passenger airbag needs to be deployed. Siemens has developed a 3-D system that can also determine the distance between the driver's head and dashboard, and limit the deployment of the airbag to only that required distance.

Work is still being done to make airbags adaptive and to inflate in two stages, or as shown in Figure 7, to detect the driver's position and distance from the dash and inflate in an appropriate manner. Add to this the control of side impact airbags and rollover curtain airbags, and the whole airbag system increases in complication.

The future

More adaptive systems are being developed, and many are starting to make their way into new vehicles. As these x-by-wire systems start to be produced and more crash-avoidance features are developed, adaptive systems will be tailored even more to the individual occupants.

Automotive technicians will not only have to be able to repair or service these systems, but also determine which ones are present and if they are working properly. Test procedures to determine the proper operation of these systems will be required. For instance, how do you determine if the adaptive lighting is operating properly in a service bay?

With the variety of models and years that an automotive technician may service, it appears that an efficient and precise method to inform a technician of just what systems are installed on a vehicle is needed. This may be even more important since some automakers are making these items optional. Will technicians need to have a "flight-like" checklist for each car and model? Only time will tell.

Miniature Load Cells

Honeywell Sensotec Products

Accelerometer
Data Sheets
DCT Instruments
Instrumentation
Miniature Load Cell
Pressure Sensor
Standard Load Cell
Torque Cells

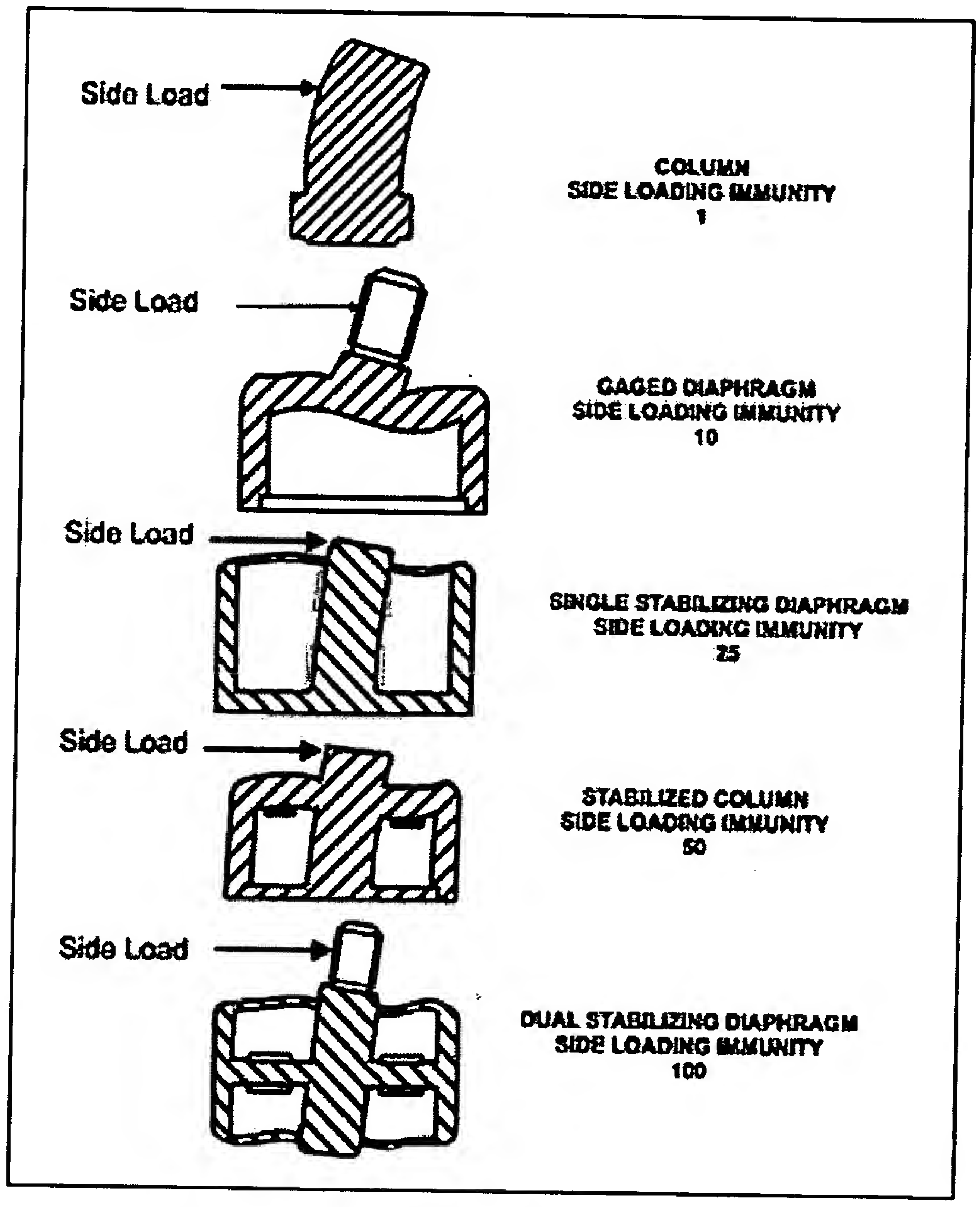
Introduction
Sizes and Form Factors
Load Ranges
High Accuracy
Choosing the Right Load Cell
Rugged Construction
Immunity to Off Axis Loading
Fully Welded Assemblies
Detailed Model Information
Mounting
Applications
Options
Submersible Version
Overload Stops
Accessories

Effects of Off Axis Loading

Off axis load carrying capacity is the ability of the sensor to take side and bending loads. As can be seen from fig 5 the column style is the most susceptible to side load and th stabilized diaphragm the least susceptible. The single diaphragm unit is better than the column but not nearly as good as the stabilized diaphragm unit.

Off axis load carrying capacity is important for two reasons: first, the ability to handle hig loads without breaking and secondly, the ability to reject extraneous load information in t output of the sensor. For example the, with the same side side loads, the single diaphrag unit will have approximately 10 times more error than the stabilized unit. Side load sensitivity can be reduced by increasing the diameters (twice the diameter is about twice strong). However increasing the physical size is not always an option.

Fig 6 Approximate relative side loading immunity



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Mounting Arrangements

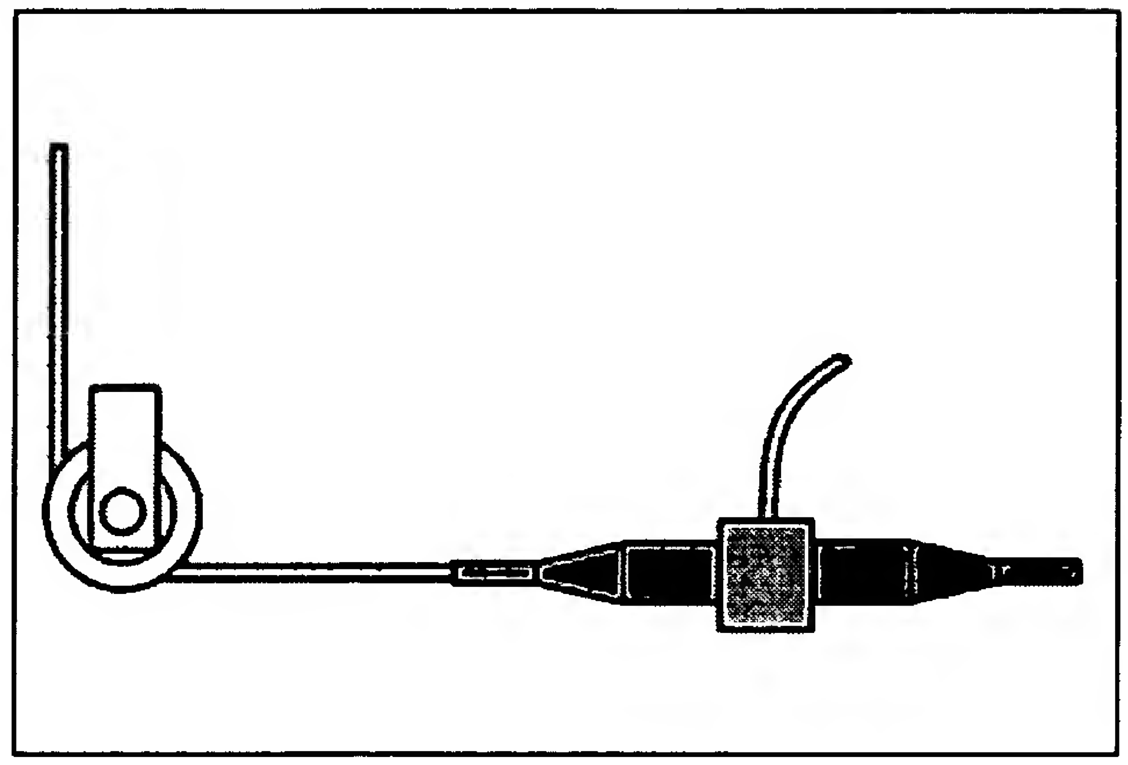

Fig 11 Model 11 or 31 typical mounting arrangement

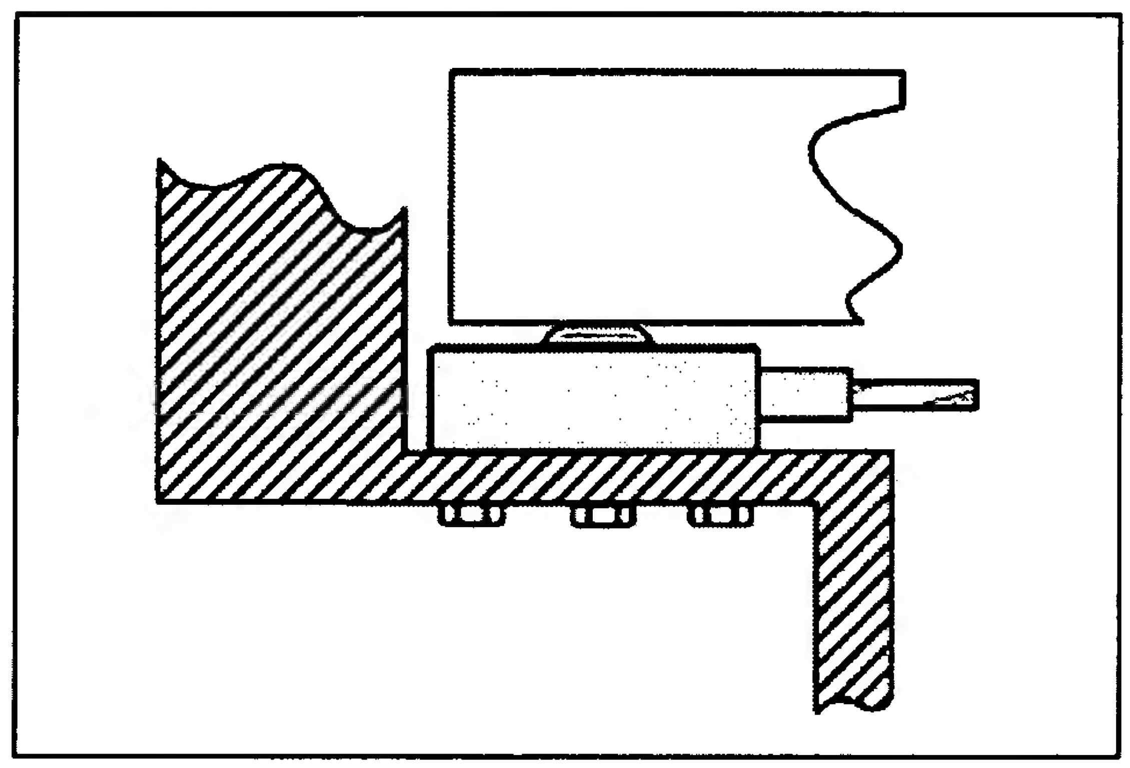

Fig 12 Model 13 or 53 typical mounting arrangement

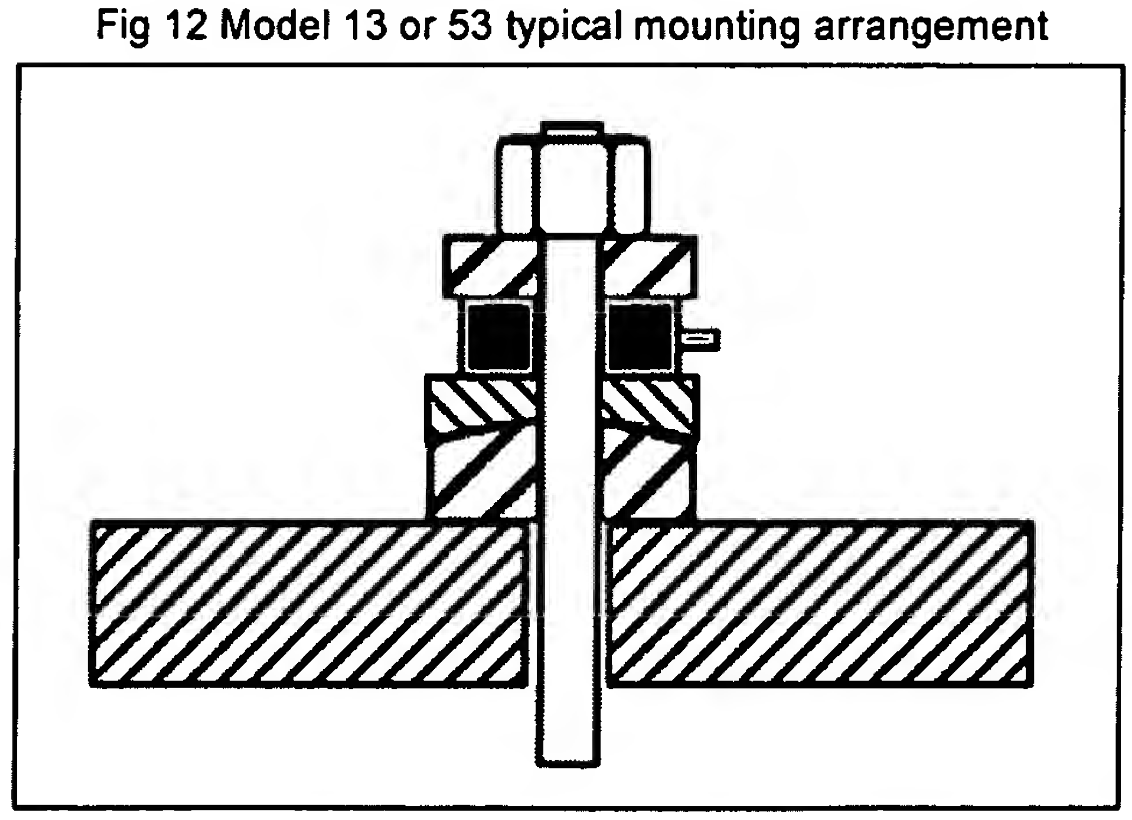

Fig 13 Model D typical mounting arrangement

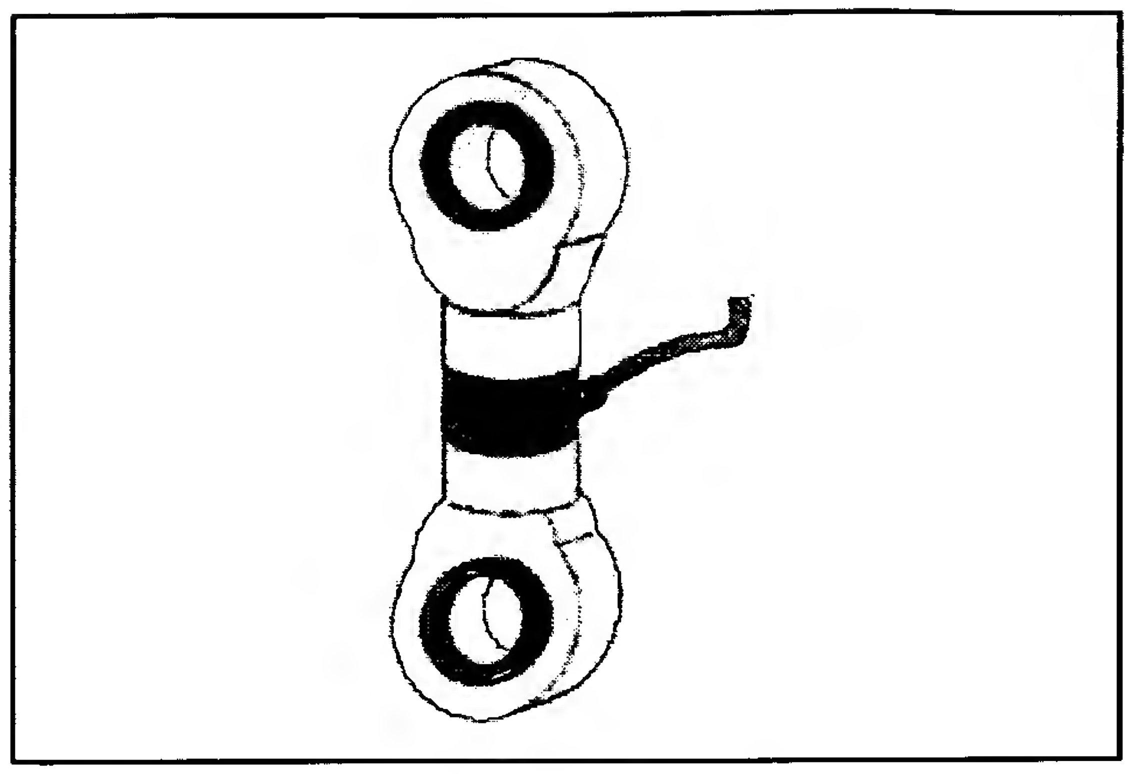

Fig 14 Model 11 or Model 31 mounting with rod end bearings

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Miniature Load Cells

Construction

There are a variety of different construction types for miniature load cells. Fig 4 shows the different type and their attributes. Often the choice of design for construction is a comprom with each design having advantages and disadvantages over other designs.

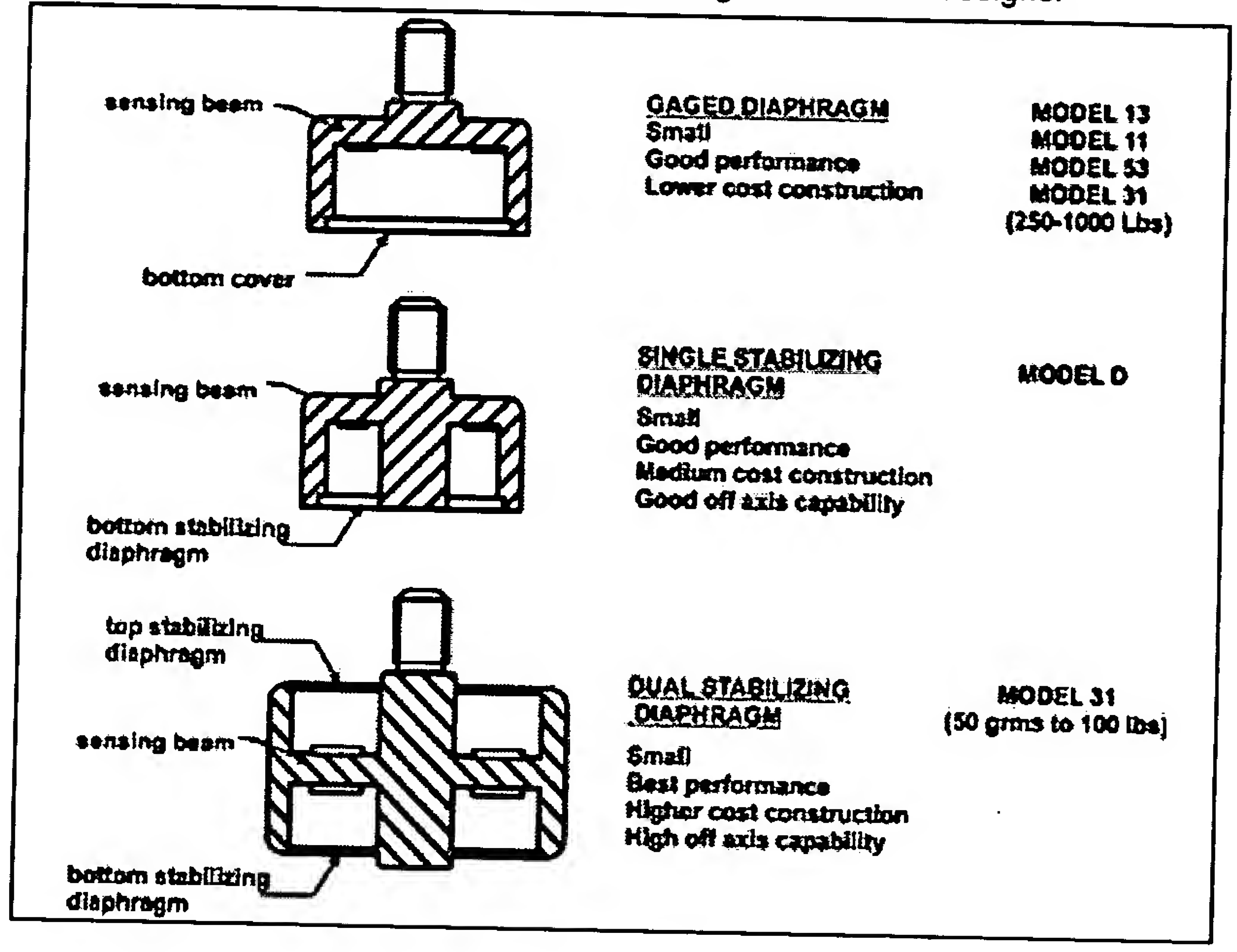

Fig 4 Honeywell Sensotec miniature load cell constructions

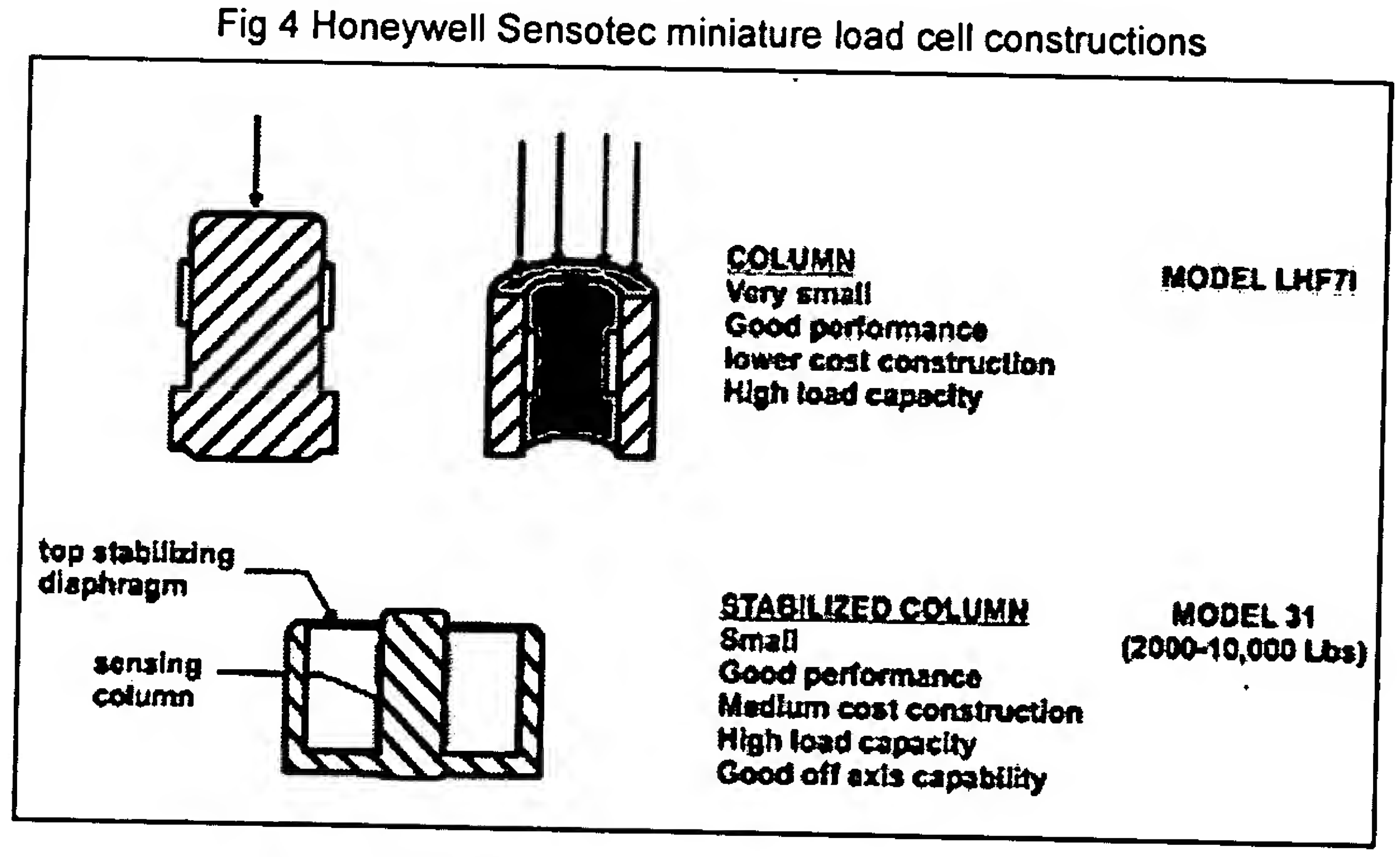

Fig 5 Honeywell Sensotec miniature load cell constructions

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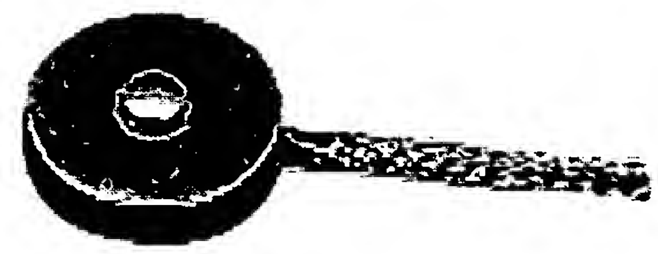
Subminiature Load Cells

Model 13



Model 13 Compression Only

150 gms to 1000 lbs.

STAINLESS STEEL

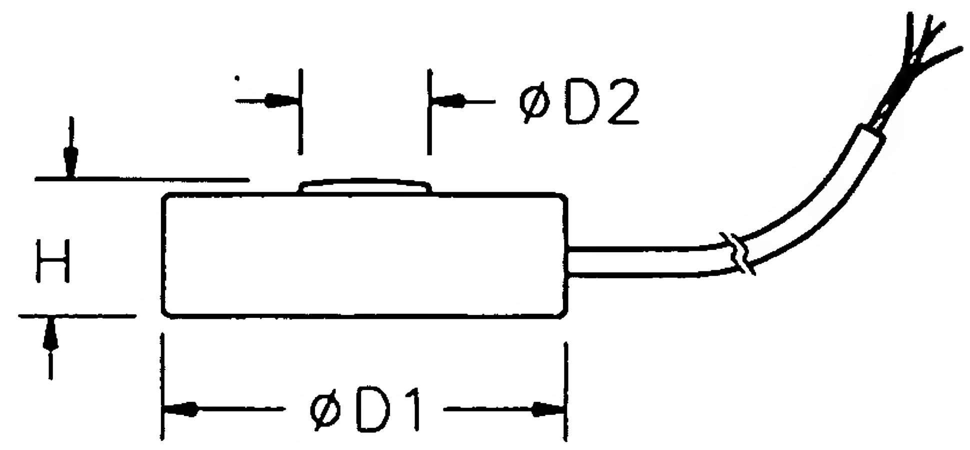
Model 13 (compression only) Subminiature Load Cell is designed to measure load ranges from 150 grams to 1000 lbs. With subminiature dimensions, including diameters from .38" to 0.75" and heights of .13" to 0.25", these units are easily incorporated into systems having limited space. Model 13 combines high frequency and low deflection to achieve a combined non-linearity and hysteresis of 0.25%-0.5% full scale. A small circuit board is included in the load cell's lead wire cable for temperature compensation, and should not be removed.

Dimensions

Model 13 (Order Code AL322)

Available Ranges*	**D1"**	**D2"**	**H"**
150; 250; 500 gms;	.375	.09	.247
1000 gms; 5; **10; 25; 50** lbs.	.38	.09	.13
100; 250 lbs.	.50	.12	.15
500; 1000 lbs.	.75	.25	.25

*Stocked ranges are in bold faced print.



PERFORMANCE

Load Ranges	150 gms to 1000 lbs.
Non-Linearity/Hysteresis (max)	
150 gms	±0.5% F.S.
1000 gms to 1000 lbs.	±0.25% F.S.
Non-Repeatability (max)	±0.1% F.S.
Output (standard)	
150 to 500 gms	15mV/V nom.
1000 gms	1.5mV/V nom.
5 lbs. to 1,000 lbs.	2mV/V nom.
Resolution	Infinite

ENVIRONMENTAL

Temperature, Operating	-65° F to 250° F
Temperature, Compensated	60° F to 160° F
Temperature Effect	
– Zero (max)	0.01% F.S./° F
– Span (max)	0.02% Rdg./° F

ELECTRICAL

Strain Gage Type	Foil or Semi-Cond.
Excitation (calibration)	
50 gms to 1000 lbs.	5VDC
Insulation Resistance	5000 megohm @ 50VDC
Bridge Resistance	
50 gms to 500 gms	500 ohm (semi)
1000 gms to 1000 lbs.	350 ohm (foil)
Shunt Calibration Data	Included
Wiring Code (std)	#1 (See Pg. AP-6)
Electrical Termination (std)	Cable exit (5 ft.)

MECHANICAL

	150g	250g	500g	1000g	5lb	10lb	25lb	50lb	100lb	250lb	500lb	1000lb
Deflection @ F.S. ($x10^3$ in)	0.06	0.06	0.08	0.04	0.5	0.4	0.4	0.4	0.5	0.6	0.6	0.8
Static Overload Capacity (% F.S.)	500	500	500	150	150	150	150	150	150	150	150	150
Ringing Frequency (kHz)	26	31	39	26	34	46	69	88	71	86	57	61
Weight (g)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	3.1	3.2	10	10

NOTES *A small 2" long circuit board is included in the cable, 2 ft. from the load cell. Do not remove this board.

Options (See Appendix)

Temperature compensated 1b, 1c

Premium Options: 1e (>1000 gms only), 1f (>1000 gms only)

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Subminiature Load Cells

Model 11

Model 11 Tension/Compression

150 gms to 1000 lbs.

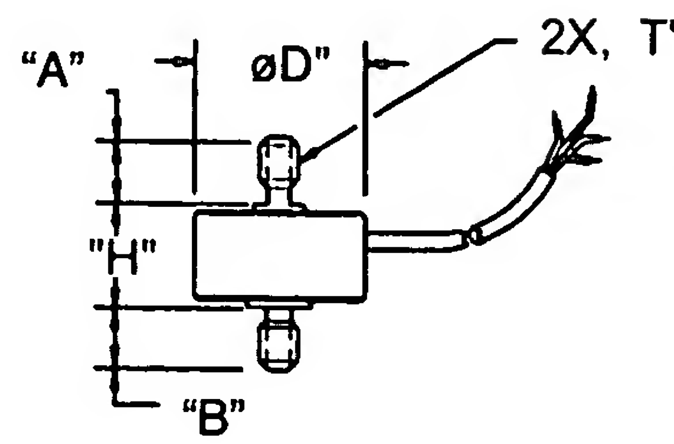
STAINLESS STEEL

Model 11 (tension/compression) Subminiature Load Cell is designed to measure load ranges from 150 grams to 1000 lbs. With subminiature dimensions, including diameters from .50" to 0.75" and height of 0.38", these units are easily incorporated into systems having limited space. The model achieves a combined non-linearity and hysteresis of 0.5% full scale and a frequency response of up to 58 kHz. A small circuit board is included in the load cell's lead wire cable for zero balance, and should not be removed.

Model 11 (Order Code BL321)

Available Ranges	øD"	T	H"	A"	B"	Q*
150; 250; 500; 1000 gms	.50	#4-40UNC	.29	.19	.18	4
5; 10; 25; 50; 100 lbs.	.50	#4-40UNC	.29	.19	.18	4
250; 500; 1000 lbs.	.75	1/4-28UNF	.38	.31	.31	20

*** "Q" = maximum tightening torque allowed inch-lbs.**



PERFORMANCE

Load Ranges	150 gms to 1000 lbs.
Non-Linearity (max)	±0.5% F.S.
Hysteresis (max)	±0.5% F.S.
Non-Repeatability (max)	±0.1% F.S.
Output (standard)	
150 gms to 500 gms	10mV/V nom.
1000 gms to 1000 lbs.	2mV/V nom.
Resolution	Infinite
Zero Balance (nom.)	± 3% F.S.

ENVIRONMENTAL

Temperature, Operating	-65° F to 250° F
Temperature, Compensated	60° F to 160° F
Temperature Effect	
– Zero (max)	0.01% F.S./° F
– Span (max)	0.02% Rdg./° F

ELECTRICAL

Strain Gage Type	
150 gms to 500 gms	Semiconductor
1000 gms to 10,000 lbs	Foil
Excitation (calibration)	5VDC
Insulation Resistance	5000 megohm @ 50VDC
Bridge Resistance	
150 gms to 500 gms	500 ohm (semi)
1000 gms to 10,000 lbs.	350 ohm (foil)
Wiring Code (std)	#1 (See Appendix)
Electrical Termination (std)	5' integral cable with balance board*

MECHANICAL

	150g	250g	500g	1000g	5lb	10lb	25lb	50lb	100lb	250lb	500lb	1000lb
Deflection @ F.S. ($x10^{-3}$ in)	0.05	0.04	0.03	0.7	0.7	0.5	0.4	0.4	0.4	1.1	1.5	2.0
Static Overload Capacity (% F.S.)	500	500	500	150	150	150	150	150	150	150	150	150
Ringing Frequency (kHz)	9.5	14	22	6.5	9.8	16	29	41	58	23	28	34
Weight (g)	5	5	5	5	5	5	5	5	5	19	19	19

NOTE: Standard calibration for tension/compression load cells is in tension only.
* A small 2" long circuit board is included in the cable, 2 ft. from the load cell. Do not remove this board.

Options (See Appendix)

Temperature compensated 1b, 1c

Premium Opti ns: 1e (>1000 gms only), 1f (>1000 gms only)

Load Cell Designs

Before strain gage-based load cells became the method of choice for industrial weighing applications, mechanical lever scales were widely used. Mechanical scales can weigh everything from pills to railroad cars and can do so accurately and reliably if they are properly calibrated and maintained. The method of operation can involve either the use of a weight balancing mechanism or the detection of the force developed by mechanical levers. The earliest, pre-strain gage force sensors included hydraulic and pneumatic designs.

In 1843, English physicist Sir Charles Wheatstone devised a bridge circuit that could measure electrical resistances. As was discussed in detail in Chapter 2, the Wheatstone bridge circuit is ideal for measuring the resistance changes that occur in strain gages. Although the first bonded resistance wire strain gage was developed in the 1940s, it was not until modern electronics caught up that the new technology became technically and economically feasible. Since that time, however, strain gages have proliferated both as mechanical scale components and in stand-alone load cells.

Today, except for certain laboratories where precision mechanical balances are still used, strain gage load cells dominate the weighing industry. Pneumatic load cells are sometimes used where intrinsic safety and hygiene are desired, and hydraulic load cells are considered in remote locations, as they do not require a power supply. Strain gage load cells offer accuracies from within 0.03% to 0.25% full scale and are suitable for almost all industrial applications.

In applications not requiring great accuracy--such as in bulk material handling and truck weighing--mechanical platform scales are still widely used. However, even in these applications, the forces transmitted by mechanical levers often are detected by load cells because of their inherent compatibility with digital, computer-based instrumentation. The features and capabilities of the various load cell designs are summarized in Figure 7-1.

Figure 7-1: Load Cell Performance Comparison

TYPE OF LOAD CELL	WEIGHT RANGE	ACCURACY (FS)	APPLICATIONS	ADVANTAGES	DISADVANTAGE
Mechanical Cells					
Hydraulic	Up to 10,000,000 lb	0.25%	Tanks, bins and hoppers. Hazardous areas.	Takes high impacts, insensitive to temperature.	Expensive, complex.
Pneumatic	Wide	High	Food industry, hazardous areas	Intrinsically safe. Contains no fluids.	Slow response. Requires clean, dry air
Strain Gage Cells					
Bending Beam	10-5,000 lb	0.03%	Tanks, platform scales,	Low cost, simple construction	Strain gages ar exposed, require protection
Shear Beam	10-5,000 lb	0.03%	Tanks, platform scales, off- center loads	High side load rejection, better sealing and	

				protection	
Canister	to 500,000 lb	0.05%	Truck, tank, track, and hopper scales	Handles load movements	No horizontal load protection
Ring and Pancake	5- 500,000 lb		Tanks, bins, scales	All stainless steel	No load movement allowed
Button and washer	0-50,000 lb 0-200 lb typ.	1%	Small scales	Small, inexpensive	Loads must be centered, no load movement permitted
Other Types					
Helical	0-40,000 lb	0.2%	Platform, forklift, wheel load, automotive seat weight	Handles off-axis loads, overloads, shocks	
Fiber optic		0.1%	Electrical transmission cables, stud or bolt mounts	Immune to RFI/EMI and high temps, intrinsically safe	
Piezoresistive		0.03%		Extremely sensitive, high signal output level	High cost, nonlinear outpu

Operating Principles

Load cell designs can be distinguished according to the type of output signal generated (pneumatic, hydraulic, electric) or according to the way they detect weight (bending, shear, compression, tension, etc.)

Hydraulic load cells are force -balance devices, measuring weight as a change in pressure of the internal filling fluid. In a rolling diaphragm type hydraulic load cell, a load or force acting on a loading head is transferred to a piston that in turn compresses a filling fluid confined within an elastomeric diaphragm chamber. As force increases, the pressure of the hydraulic fluid rises. This pressure can be locally indicated or transmitted for remote indication or control. Output is linear and relatively unaffected by the amount of the filling fluid or by its temperature. If the load cells have been properly installed and calibrated, accuracy can be within 0.25% full scale or better, acceptable for most process weighing applications. Because this sensor has no electric components, it is ideal for use in hazardous areas.

One drawback is that the elastomeric diaphragm limits the maximum force that can be exerted on the piston to about 1,000 psig. All-metal load cells also are available and can accommodate much higher pressures. Special metal diaphragm load cells have been constructed to detect weights up to 10,000,000 pounds.

Typical hydraulic load cell applications include tank, bin, and hopper weighing. For maximum accuracy, the weight of the tank should be obtained by locating one load cell at each point of support and summing their outputs. As three points define a plane, the ideal number of support points is three. The outputs of the cells can be sent to a hydraulic totalizer that sums the load cell signals and generates an output representing their sum. Electronic totalizers can also be used.

Pneumatic load cells also operate on the force-balance principle. These devices use multiple dampener chambers to provide higher accuracy than can a hydraulic device. In some designs, the first dampener chamber is used as a tare weight chamber. Pneumatic load cells are often used to measure relatively small weights in industries where cleanliness and safety are of prime concern.

The advantages of this type of load cell include their being inherently explosion proof and insensitive to temperature variations. Additionally, they contain no fluids that might contaminate the process if the diaphragm ruptures. Disadvantages include relatively slow speed of response and the need for clean, dry, regulated air or nitrogen.

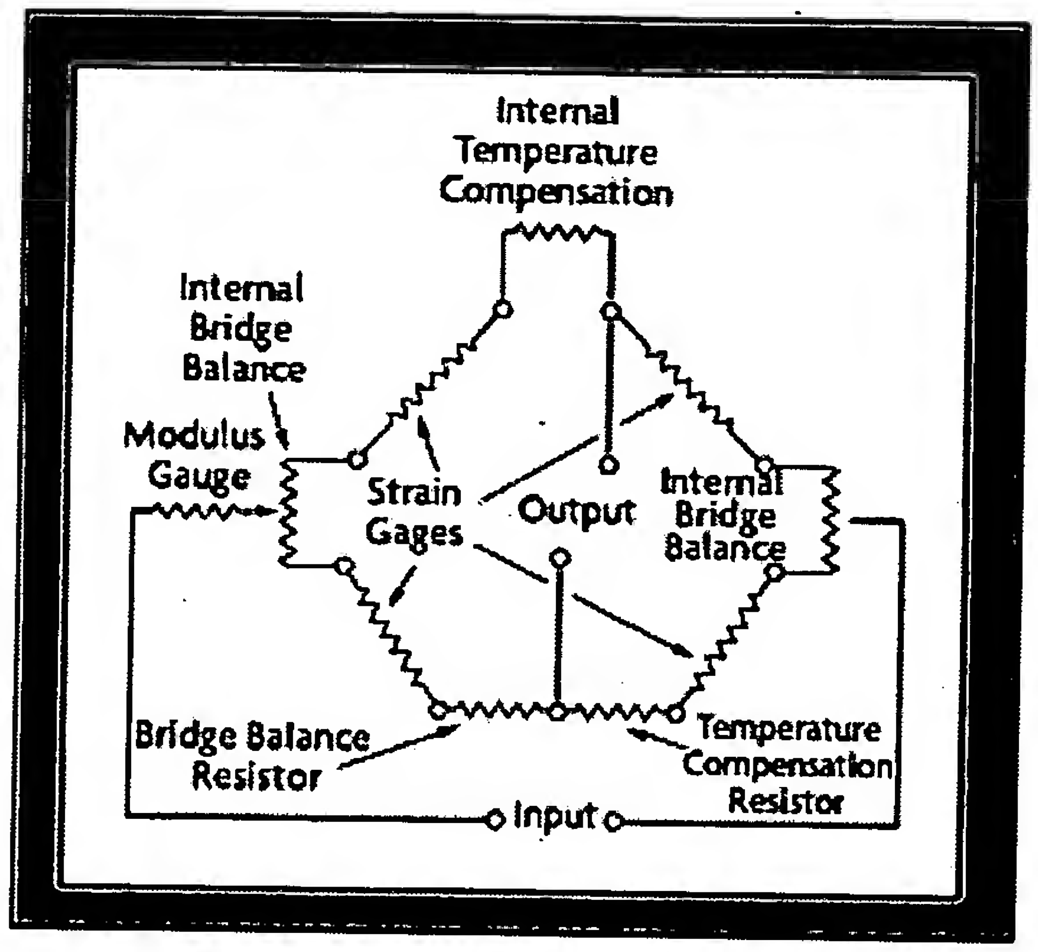
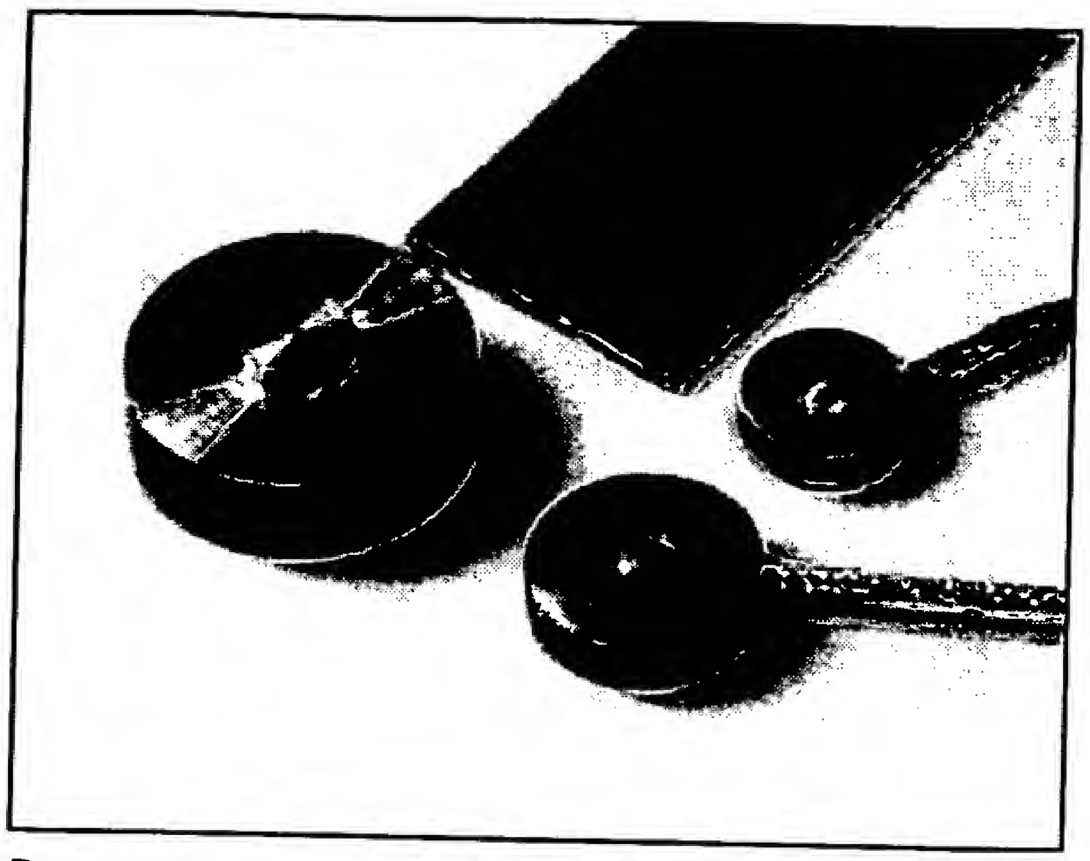


Figure 7-2: Wheatstone Circuit with Compensation

Strain-gage load cells convert the load acting on them into electrical signals. The gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. In most cases, four strain gages are used to obtain maximum sensitivity and temperature compensation. Two of the gauges are usually in tension, and two in compression, and are wired with compensation adjustments as shown in Figure 7-2. When weight is applied, the strain changes the electrical resistance of the gauges in proportion to the load.

Other load cells are fading into obscurity, as strain gage load cells continue to increase their accuracy and lower their unit costs. Some designs, however do continue to enjoy limited use:

Piezoresistive: Similar in operation to strain gages, piezoresistive sensors generate a high level output signal, making them ideal for simple weighing systems because they can be connected directly to a readout meter. The availability of low cost linear amplifiers has diminished this advantage, however. An added drawback of piezoresistive devices is their nonlinear output.



Button style compression load cells.

Inductive and reluctance: Both of these devices respond to the weight-proportional displacement of a ferromagnetic core. One changes the inductance of a solenoid coil due to the movement of its iron core; the other changes the reluctance of a very small air gap.

Magnetostrictive: The operation of this sensor is based on the change in permeability of ferromagnetic materials under applied stress. It is built from a stack of laminations forming a load-bearing column around a set of primary and secondary transformer windings. When a load is applied, the stresses cause distortions in the flux pattern, generating an output signal proportional to the applied load. This is a rugged sensor and continues to be used for force and weight measurement in rolling mills and strip mills.

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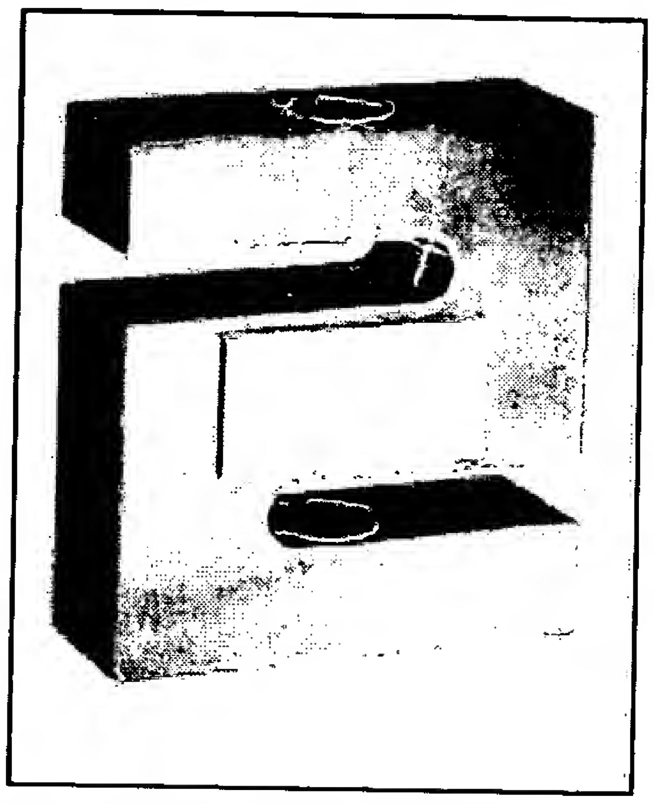
Next Chapter: Load Cell Designs Continued

Load Cell Designs

New Sens r Devel pments

In the area of new sensor developments, fiber optic load cells are gaining attention because of their immunity to electromagnetic and radio frequency interference (EMI/RFI), suitability for use at elevated temperatures, and intrinsically safe nature. Work continues on the development of optical load sensors. Two techniques are showing promise: measuring the micro-bending loss effect of single-mode optical fiber and measuring forces using the Fiber Bragg Grating (FBG) effect. Optical sensors based on both technologies are undergoing field trials in Hokkaido, Japan, where they are being used to measure snow loads on electrical transmission lines.



"S" beam load cells for compression or tension applications.

A few fiber optic load sensors are commercially available. One fiber optic strain gage can be installed by drilling a 0.5 mm diameter hole into a stud or bolt, and then inserting the strain gage into it. Such a sensor is completely insensitive to off-axis and torsion loads.

Micromachined silicon load cells have not yet arrived, but their development is underway. At the Universiteit Twente in the Netherlands, work is progressing on a packaged monolithic load cell using micromachining techniques, and it is possible that silicon load cells might dominate the industry in the future.

Next Chapter: Load Cell Designs Continued

Kalman Filter for Dynamic Weighing System

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Abstract **In the area of mass production, products are weighed using load cell based dynamic weighing systems. A load cell is an uncontrollable weighing device and the value of weight, for the passing product, is estimated by filtering the electrical signal from a load cell. Improvement in filtering increases the speed of weighing and enhances the measurement accuracy. In this paper a Kalman filter is proposed as a weight filter for the dynamic weighing system. Furthermore, the paper includes mathematical models of the load cell and forcing functions. These models are used to examine the suitability of the proposed Kalman filter approach. Since this approach is based on the accurate model of the system in question, the exact model of the load cell based dynamic weighing system has been derived and presented. For one particular value of the weight, the parameters of the model are time-varying due to the product coming onto the weigh-table and due to the product length. Changing the measurement from one value of the weight to another, causes even greater changes in the values of the model parameters and introduces a non-linearity in the system. Therefore, an adaptivity approach has been considered and a solution proposed. The simulation and experimental results are presented and compared. The results achieved, show that the Kalman filter may provide effective alternative to the conventional method especially when the system is non-linear and low frequency noise is incorporated in the bandwidth of the useful signal.**

Keywords: **Dynamic weighing system, Modelling, Kalman Filter, Estimation, Simulation.**

1. INTRODUCTION

The weighing of articles is an essential part of modern life. There is a constant need for knowing the exact weight of many items, e.g., food, ingredients for production, pharmacology, chemistry, technology, etc. The type and the number of products that require weight control are increasing. Consequently, the legal requirements of government bodies, internationally, are trying to maintain the same constant pace. In production, this means high accuracy and efficiency of weighing are also constantly high on the agenda. Continuation of this trend brings benefits for both the customer and the producer. That is, manufacturing efficiency is increased and hence profitability whilst package quality and quantity are assured to the customer's satisfaction.

In the area of mass production, products are weighed using industrial weighing systems, which are machines that weigh a package dynamically. The weight of the package is estimated while the product has been carried over a weightable by a transport system. Normally, the transport system is of a conveyer belt type. The weightable is mounted on a load cell, which is the uncontrollable weighing device capable of weighing an article. A signal processing module (SPM) acquires the electrical signal from weighing device and estimates a value of weight for the passing product as its output. The two main aims for improvement are: (1) to increase the speed of weighing and (2) to achieve good measurement accuracy. Improvement in SPM that provides any one or both of those aims brings significant benefit to the overall dynamic weighing system. Fig. 1. shows product flow and the weighing process.

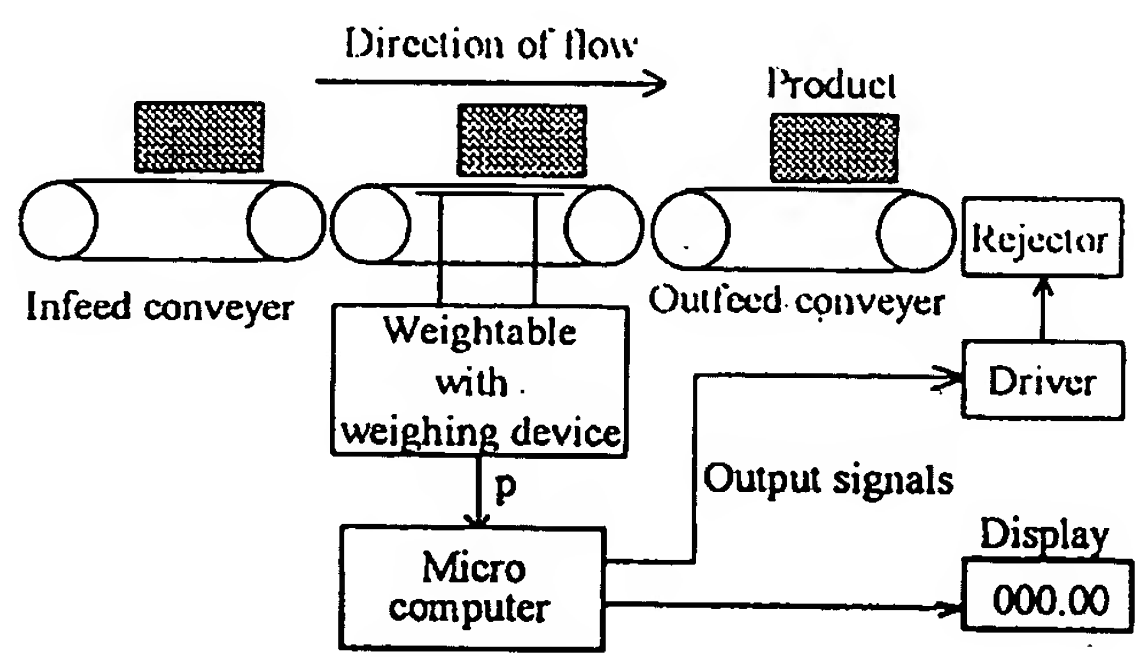

Fig. 1. Product flow and weighing process.

2. BACKGROUND

The main constrain in achieving higher accuracy and/or increasing throughput rate of the passing products is a superimposed noise on a useful signal from dynamic weighing systems. The sources of the noise are the dynamic

IEEE Catalog Number: 95TH8081

weighing system and measurement. The noise that comes from the system is termed system noise and pre-dominantly comes from mechanical and electrical part of weighing system and from the type of the product. Significant contribution to the noise comes from the speed of the conveyer belt. The level and frequency components of the spectrum of the noise changes with speed of the conveyer belt. To extract desired part of the signal, it is necessary to find a filter technique that will cope with changes of the noise frequency characteristics and gives both fast transient response and a stable and robust weighing result. From filter theory it is known that linear phase filters are the best with respect to transient response time. Therefore, in an analog realisation of the filter, Bessel low-pass filters with nearly linear phase response prove to be most suitable. Regarding digital realisation of filters, the analysis has been performed in order to choose the most suitable type of digital filter. FIR filter with smooth cut-off frequency characteristics, linear phase response and features to retain the shape of the signal has proven to be the most appropriate one. Also, the use of Hann's or Hamming's window ensures an acceptable level of ripple. The cut-off frequency of the filter is related to the bandwidth of the desired signal, while the order of the filter depends on the magnitude of the noise. The desired part of the signal has been found by using multiple time averaging (MTA) method. This method is applied to 100 measurement of the data taken for the same product at the same speed of the conveyer belt. Afterwards, the bandwidth was calculated based on the assumption that 99.7% of the signal power is concentrated in its bandwidth.

$$P = \frac{1}{N}\sum_{i=0}^{N-1}\left|X_i\right|^2 \qquad (1)$$

where:

$|X_i|$ - components of magnitude of I FFT I spectrum

The analysis of noise gives information to estimate the order of the filter. On the basis of this knowledge and trial and error method, the best results that have been obtained for two different speeds of conveyer belt are as follows:

Belt speed in m/min	Type of filter	Value of the cut-off frequency	Order of the filter
20	FIR with Hann's window	5	131
100	FIR with Hann's window	8	40

Using the analytical method and trial and error technique to determine optimal filter parameters is time consuming. Therefore, an automatic method has been developed [4], in which the filter parameters are optimised using the performance indices as the quality of the filter (Q).

$$1/Q = \frac{STD}{MEAN}$$

where:

STD ---- standard deviation of the filtered signal
MEAN - mean value of filtered signal

This method is implemented using a computer, hence the optimal parameters can be achieved in relatively shorter time (up to about 15 minutes of simulation time). The cut-off frequency and the order of the filter have been varied within certain range, automatically through the software simulation program, trying to find maximal value of the quality of the filter Q. Simulation has been performed for various operating condition in a way that changing the type of product and the speed of the conveyer belt have been enabled. The results that have been obtained with automatic design approach agreed well with the results from the previous filter design procedure. Afterwards, the original signal from a dynamic weighing system has been filtered with the best found filter and it is shown in Fig. 2.

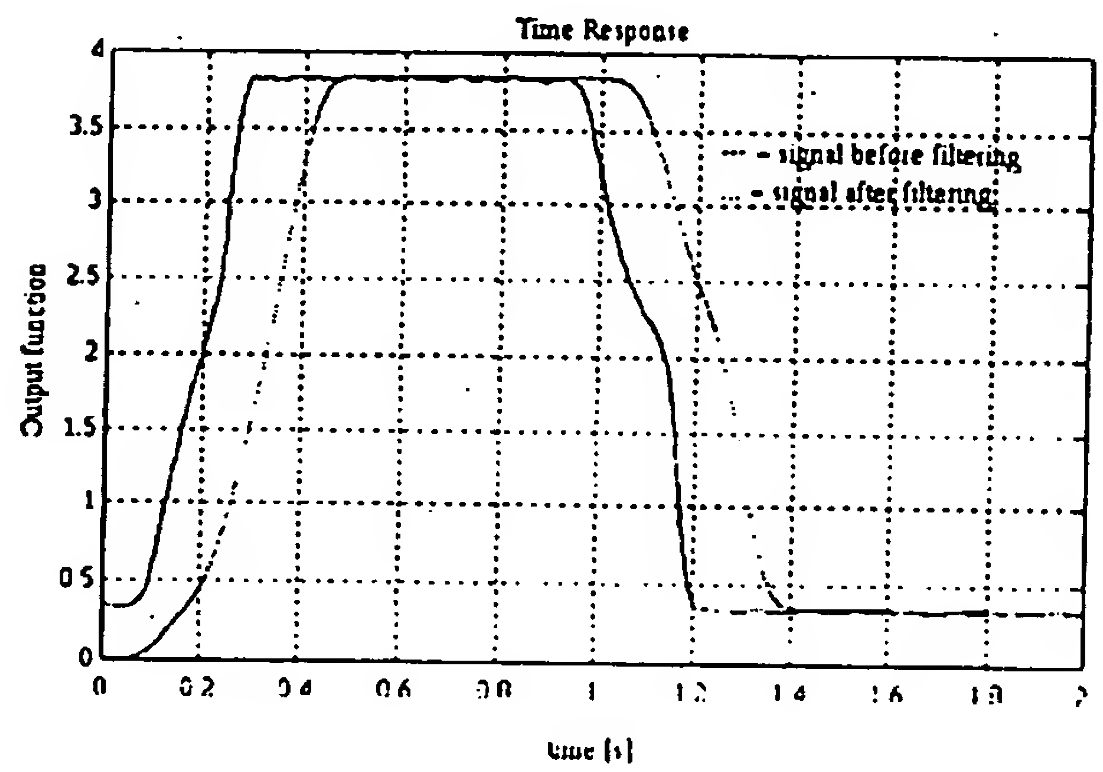

Fig. 2. Measurement signal filtered with FIR filter with Hann's window.

The results that have been obtained for single weighing measurement have shown improvement of 150%. However, the results for repeated measurements showed only 5% improvement. The reason is the fluctuation of a DC level with very low frequency, from measurement to measurement. This indicates that the system is non stationary and further improvement in repeated measurement is possible only by eliminating the variati n f the mean value from

measurement to measurement. It is known from theory that Kalman filter is a useful tool for reducing the effects of noise in measurements. It estimates the new value of the variable with the minimal variance. Theref re, in the next sections we have considered using Kalman filter to determine the true DC level of our measurement signal.

3. KALMAN FILTER APPROACH

A Kalman filter is a method of estimating the true value of a set of variables from a set of noisy measurements. It is known from the theory that the best estimate of the variable (i.e., our DC level) at the time (k+1) is given by a weighted mean:

$$\hat{x}(k+1) = (1-K(k))\hat{x}(k) + Ky(k) \tag{2}$$

where:

- x - estimate of the variable
- y - measurement of the variable
- K - the value that tells us how much notice to take of old estimate compared with the new measurement.

This technique gives us a method for calculating K in an optimal way with respect to minimal variance of estimation.

Suppose we have a linear discrete-time system given in a state space description:

$$\begin{aligned} x(k+1) &= A(k)x(k) + B(k)u(k) + z(k) \\ E\{x(0)\} &= x_0 \\ y(k) &= C(k)x(k) + v(k) \end{aligned} \tag{3}$$

where:

- x(k) - state of the system,
- x(0) - initial state; gaussian random variable with mean $E\{x(0)\}=x_0$ and covariance R_0,
- u(k) - input of the system,
- y(k) - output of the system,
- A(k), B(k) and C(k) - matrices of appropriate dimension,
- z(k) - system noise with covariance R_z,
- v(k) - measurement noise with covariance R_v.

The value of the state from equation (3) could be estimated with respect to equation (2) as follows:

$$\hat{x}(k+1) = A(k)\hat{x}(k) + B(k)u(k) + K(k)[y(k) - C(k)\hat{x}(k)] \tag{4}$$

The gain matrix K is calculated in such a way that the variance of the new estimate is minimum. A covariance matrix for the new estimate could be expressed as:

$$P(k+1) = E\left\{\left[\hat{x}(k+1) - E\{\hat{x}(k+1)\}\right]\left[\hat{x}(k+1) - E\{\hat{x}(k+1)\}\right]^T\right\} \tag{5}$$

Substituting (3) in (4) and expanding P(k+1) gives:

$$P(k+1) = [A(k) - K(k)C(k)]P(k)A^T(k) + R_Z(k) \tag{6}$$

To get the best estimate of x(k+1), K(k) should be calculated in a manner that minimises the covariance matrix P(k+1). It means that the following condition should be fulfilled:

$$\frac{dP(k+1)}{dK(k)} = 0 \tag{7}$$

Hence:

$$K(k) = A(k)P(k)C^T(k)[R_V(k) + C(k)P(k)C^T(k)]^{-1} \tag{8}$$

with the initial condition $P(0) = P_0$

where $P_0 = E\left\{[x(0) - E\{x(0)\}][x(0) - E\{x(0)\}]^T\right\}$

Knowing all covariances and initial values, substitution of equation (8) in (4) gives the best new estimate with respect to the minimal variance. The relationship of the Kalman filter to the actual system is illustrated in the block diagram of Fig. 3.

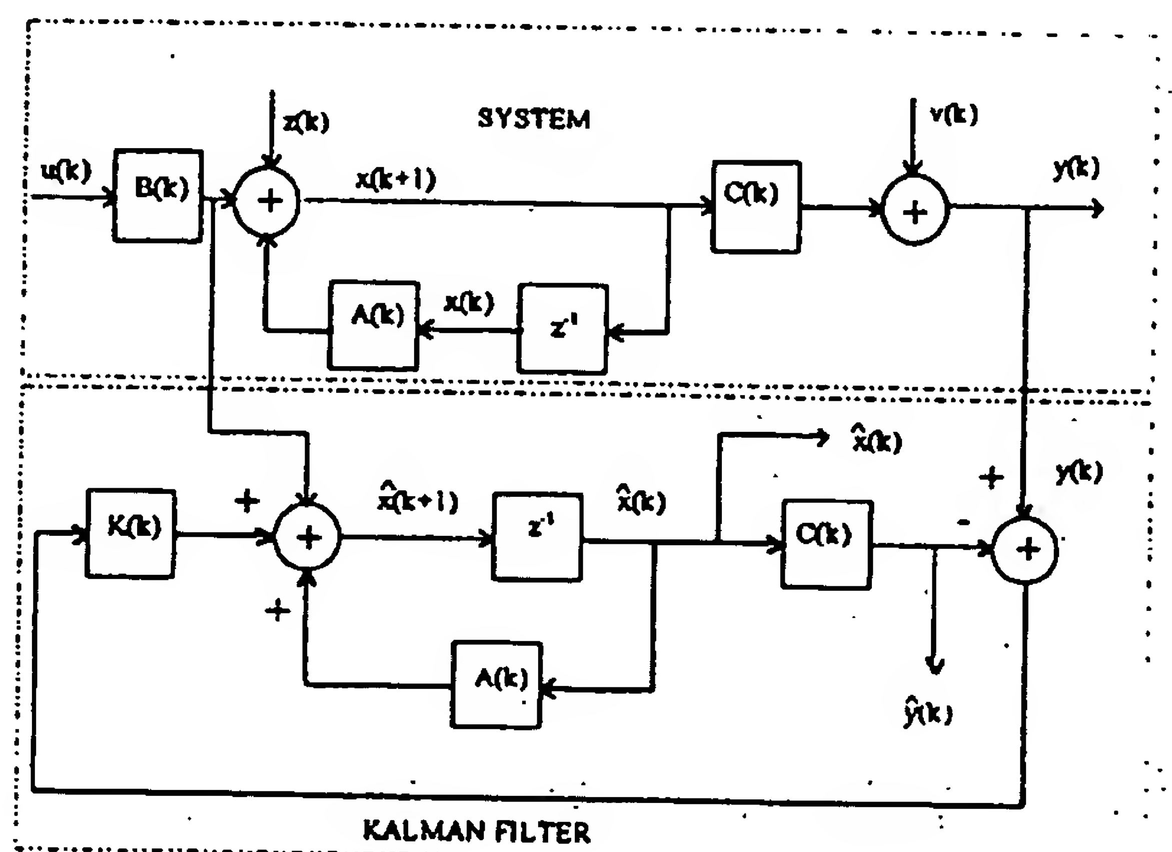

Fig. 3. Kalman filter structure connected to the system.

4. MODELLING

A. Modelling of load cell

To design a Kalman filter, the mathematical model of the physical process should be known. This is to enable us to

estimate what the values of the required variables will be, based upon our estimates of their current values. In this case the physical process is a load cell, the model of which could be derived in terms of physical laws. The type of the load cell used in this paper is the Tedea-Hunteigh 240 load cell. This load cell can be considered as a damped spring system [5].

When a product comes onto the weightable, it causes the weightable to move, and this can be described by the following differential equation:

$$(w(t)+m_l)\ddot{\theta}(t)+c\dot{\theta}(t)+k\theta(t)=w(t)g \tag{9}$$

r

$$\ddot{\theta}(t)+\frac{c}{w(t)+m_l}\dot{\theta}(t)+\frac{k}{w(t)+m_l}\theta(t)=\frac{w(t)g}{w(t)+m_l} \tag{10}$$

where

- w(t) - the mass of a product,
- m_l - the mass of the load cell itself,
- c - damping coefficient,
- k - spring stiffness,
- θ - the position of the weightable.

Defining the state variables $\xi_1(t)=\theta(t)$ and $\xi_2(t)=\dot{\theta}(t)$, the state differential equation of the system combined with equation (10) becomes:

$$\begin{aligned}&\dot{\xi}_2(t)+\frac{c}{w(t)+m_l}\xi_2(t)+\frac{k}{w(t)+m_l}\xi_1(t)=\frac{w(t)g}{w(t)+m_l}\\&\dot{\xi}_2(t)=-\frac{k}{w(t)+m_l}\xi_1(t)-\frac{c}{w(t)+m_l}\xi_2(t)+\frac{g}{w(t)+m_l}w(t)\end{aligned} \tag{11}$$

or

$$\begin{bmatrix}\dot{\xi}_1(t)\\ \dot{\xi}_2(t)\end{bmatrix}=\begin{bmatrix}0 & 1\\ -\frac{k}{w(t)+m_l} & -\frac{c}{w(t)+m_l}\end{bmatrix}\begin{bmatrix}\xi_1(t)\\ \xi_2(t)\end{bmatrix}+\begin{bmatrix}0\\ \frac{g}{w(t)+m_l}\end{bmatrix}w(t) \tag{12}$$

Let $x(t)=\begin{bmatrix}\xi_1(t)\\ \xi_2(t)\end{bmatrix}$; $\alpha(t)=-\frac{k}{w(t)+m_l}$; $\beta(t)=-\frac{c}{w(t)+m_l}$; $\gamma(t)=\frac{g}{w(t)+m_l}$; $u(t)=w(t)$ and the controlled variable y(t) be the position of the weightable. Then, the state differential equation in the matrix form is:

$$\begin{aligned}&\dot{x}(t)=\begin{bmatrix}0 & 1\\ \alpha(t) & \beta(t)\end{bmatrix}x(t)+\begin{bmatrix}0\\ \gamma(t)\end{bmatrix}u(t)+z(t)\\&y(t)=\begin{bmatrix}1 & 0\end{bmatrix}x(t)+v(t)\end{aligned} \tag{13}$$

or

$$\begin{aligned}&\dot{x}(t)=A(t)x(t)+B(t)u(t)+z(t)\\&y(t)=Cx(t)+v(t)\end{aligned} \tag{14}$$

where:

- x(t) - state of the mechanical system,
- u(t) - system input (w(t) unknown mass of a product),
- z(t) - stochastic disturbances (system noise with covariance R_z),
- y(t) - system output (position of balance beam),
- v(t) - measurement noise (Gaussian zero mean white noise with covariance R_v),
- A(t) & B(t) - time varying matrices,
- C - constant matrix.

B. Modelling of forcing functions

Apart from knowing the model of a system, it is necessary to have the model of the article to be weighed. The model should describe how the article moves onto the weightable. This is essentially the input to the load cell. Due to different reaction of articles with load cell, three forcing functions are suggested in [7] for the two package types:

a) Rigid/solid type, e.g., carton box or plastic container, tin, etc. - equation (15),
b) Loose/soft type, e.g., plastic film bag filled with powder - equations (16, 17).

The first forcing function $f_1(t)$ is a ramp function

$$f_1(t)=\frac{m}{t}\left[t-t(t-T)u(t-T)\right] \tag{15}$$

where:

u(t-T) - Heavyside unit step function;
m - mass of the package;
T - time to cover the weighing device
(T = package length L/belt speed v)

The second forcing function is a sinusoidal function:

$$f_2(t)=\begin{cases}0 & for\cdot t\le 0\\ m\cdot\sin(\omega_1 t) & for\cdot 0<t\le \pi/2\cdot\omega_1\\ m & for\cdot t\ge \pi/2\cdot\omega_1\end{cases} \tag{16}$$

The third forcing function is a cosinusoidal function:

$$f_3(t)=\begin{cases}0 & for\cdot t\le 0\\ m/2\,(1-\cos(\omega_2 t)) & for\cdot 0<t\le \pi/\omega_2\\ m & for\cdot t\ge \pi/\omega_2\end{cases} \tag{17}$$

All three functions are simulated and presented in Fig. 4

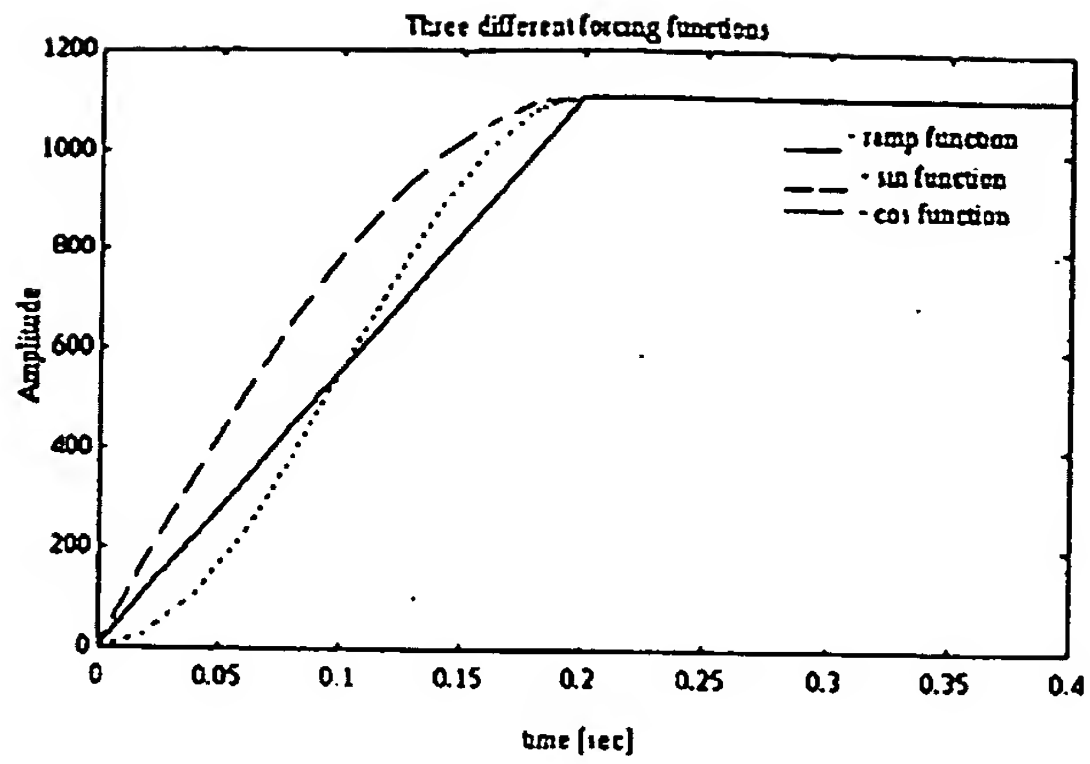

Fig. 4. Three forcing functions for two package types.

5. EXAMPLE AND SIMULATION

In this example the model of the load cell described by equation (13) is utilised. Since we are interested in the values of the system parameters when a product is completely on a weightable, the matrices A(t) and B(t) have been considered as constant matrices. Let the values of the parameters of equation (13) for the mass of 1100g are:

$$\alpha = -\frac{k}{w+m_l} = -0.383; \qquad \beta = -\frac{c}{w+m_l} = -118.774;$$

$$\gamma = \frac{g}{w+m_l} = 0.376; \qquad R_z=680; \qquad R_v=1;$$

Now, equation (13) could be written as follows:

$$\begin{aligned} \dot{x}(t) &= \begin{bmatrix} 0 & 1 \\ -0.383 & -118.774 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0.376 \end{bmatrix} u(t) + z(t) \\ y(t) &= \begin{bmatrix} 1 & 0 \end{bmatrix} x(t) + v(t) \end{aligned} \tag{18}$$

To filter a signal from dynamic weighing systems, digital computers have been used. Since, dynamic weighing system is continuous-time system there must be some form of interconnections between these two systems. In this case the interface contains an Analog-Digital-Converter of a very simple type known as zero-order hold. In such systems, to carry out simulation a discretization of the mathematical model of the dynamic weighing system has to be performed initially. The sampling period used in this example is: T_s=0.002s. After discretization, equation (18) becomes:

$$\begin{aligned} x(t) &= \begin{bmatrix} 1.000 & 0.0018 \\ -0.0007 & 0.7886 \end{bmatrix} x(t) + \begin{bmatrix} 0.0000 \\ 0.0007 \end{bmatrix} u(t) + z(t) \\ y(t) &= \begin{bmatrix} 1 & 0 \end{bmatrix} x(t) + v(t) \end{aligned} \tag{19}$$

The covariance of the system noise, R_z is considered to be a measure of the level of confidence in the given model of the load cell. It arises from the state error covariance between the system and the model of the system. Its value has been determined using performance indices as quality of filter Q, which is described in Section 2. In our case, R_z has a relatively large value. This generates relatively large gain K, which effectively put a greater emphasis on the incoming measurement. The covariance of the measurement noise, R_v has been determined from the output of the dynamic weighing system. Since the real input in the dynamic weighing system is not known, the Kalman filter uses the output of the system as its only input. Simulation is first performed with simulated noise data as output of the system and the result is depicted in Fig. 5. Afterwards, the Kalman filter is applied on a real measurement data from a dynamic weighing system. The results that have been obtained for single weighing measurement have shown improvement of 300%, while the results for repeated measurements showed 50% improvement. This is significant improvement comparing to the results obtained using other filtering techniques. Fig. 6. shows a real measurement data from a dynamic weighing system filtered with the Kalman filter.

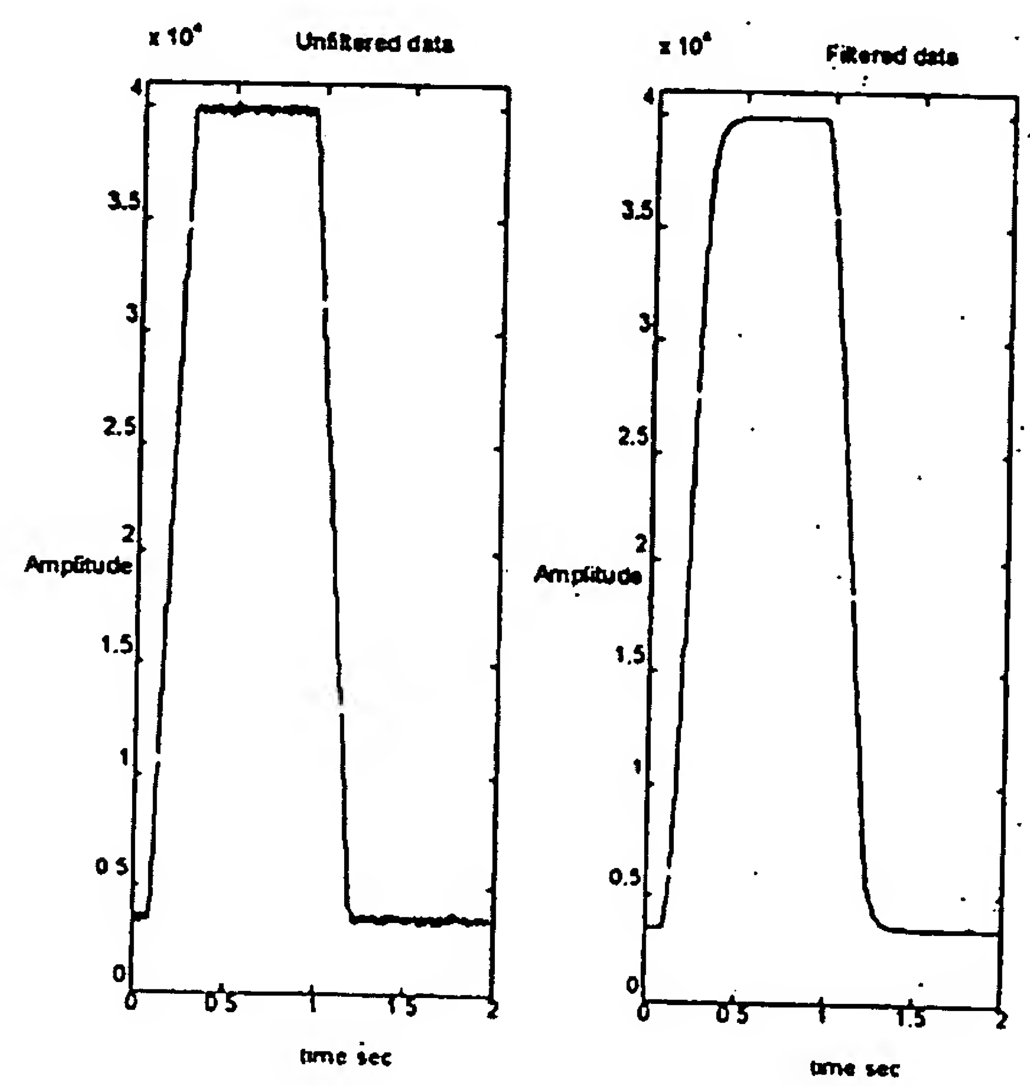

Fig. 5. Simulated data filtered with Kalman filter

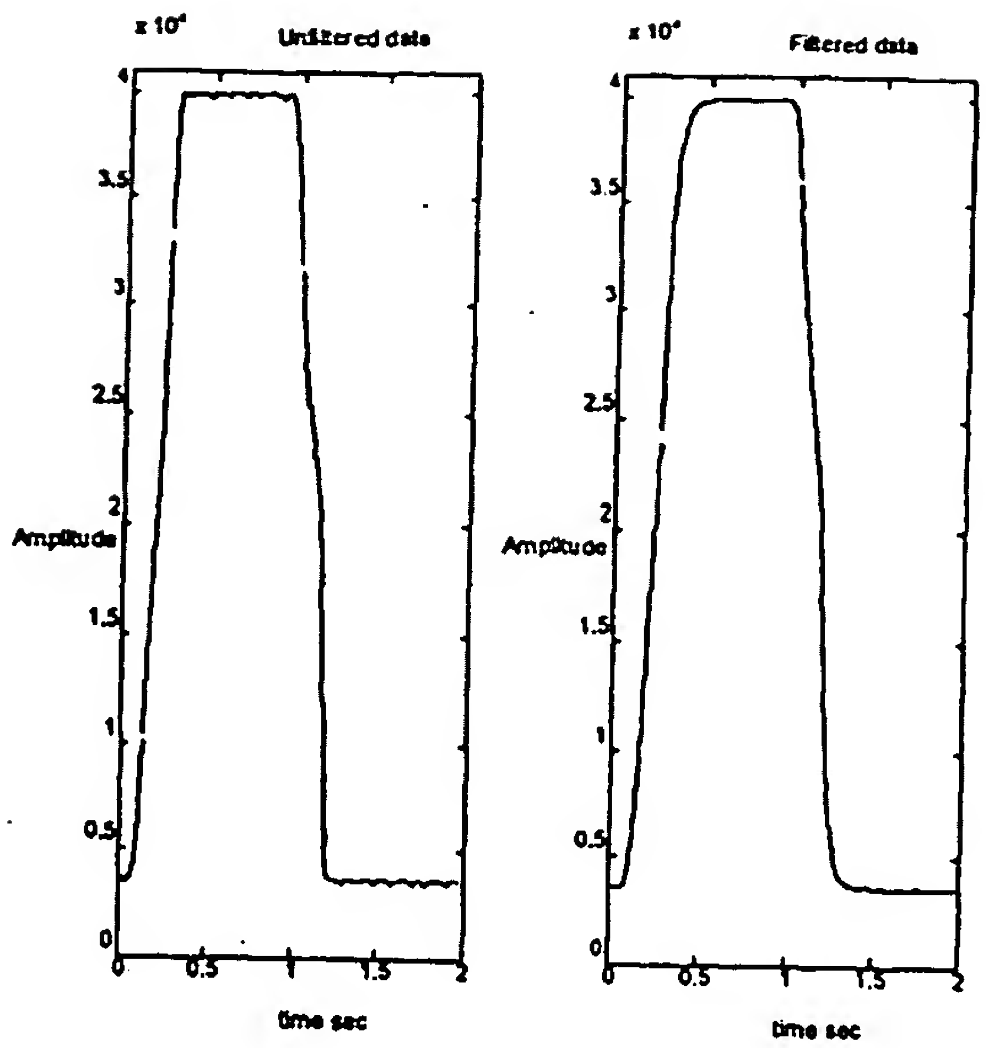

Fig. 6. Measurement data filtered with Kalman filter

The example given above clearly shows that the Kalman filter could be used for optimal filtering in dynamic weighing systems. Both, measurement accuracy and throughput rate could be increased without a reduction in one or the other. The condition, which should be fulfilled, is that the system is properly identified, i.e., all system matrices and influences of the system and measurement noise on states of the system must be known.

The model of the load cell used is linear. In reality, a dynamic weighing system is non-linear. Many non-linear systems can be approximated to a linear system over the range of interest. Therefore, linear optimal filtering may be applied to non-linear systems operating over a small signal range. The dynamic weighing system, for a given application (particular article's weight and speed of conveyer belt) could be approximated to a linear system, for which a sufficiently good linear optimal filter solution could be found. Since the dynamic weighing systems are used for different applications and conditions, adaptive filtering should be considered and applied. This could be implemented either by applying a learning phase for each particular weighing condition or by using variance matrix of the system noise that are changeable to the weighing condition. Another method could be to determine the linear optimal filter solutions for a few particular weighing conditions. Solutions for other weighing conditions can then be obtained by using intelligent interpolation techniques.

6. CONCLUSION

In dynamic weighing systems conventional filtering methods employed have limitation in improving accuracy and throughput rate. In this study, an alternative technique has been explored to find a solution that will enable measurement accuracy and throughput rate of article weighing to be increased. Mathematical model of the load cell and the article forcing functions for the load cell input were derived. A solution to filter the signal from load cell based dynamic weighing system is proposed based on Kalman filter. The general view of the use of a Kalman filter scheme in dynamic weighing systems is presented. Simulations performed on the model of the dynamic weighing system showed that Kalman filter can be employed in a practical system. This was verified using the data obtained from an industrial load cell based dynamic weighing system.

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